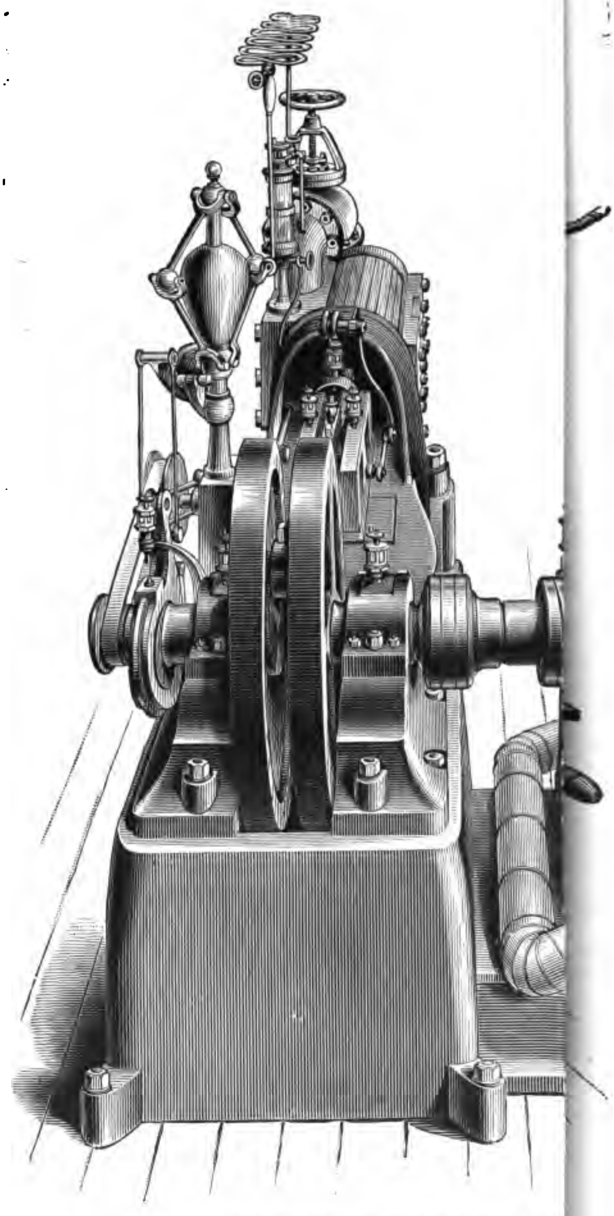

EDISON TWELVE-HUN

ELECTRICITY

IN THEORY AND PRACTICE;

OR,

THE ELEMENTS

OF

ELECTRICAL ENGINEERING.

BY

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Gift
Mrs. H. M. Langdon
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PREFACE.

THE design of this book is to form a bridge between the many works written on the theory of electricity and the many works written on its practical applications. It has been my experience that practical men and students have found great difficulty in seeing the relation between the theory of electricity and its practical applications, because they have had to study the theory from books devoted wholly to abstruse theory, and the practical applications from books devoted wholly to the practical applications. I have, moreover, been often told by practical men that a book showing the principles upon which practice depends, and explaining *the theory of the practical applications*, would be a help to many. This want I have tried to meet. May be my endeavor will at least serve to stimulate abler hands to labor in what seems to me a very useful field.

I owe much to the leading electrical journals: the New York *Electrician*, *Electrical Review*, and *Electrical World*, the London *Electrical Review* and *Electrician*, and *La Lumière Électrique*, as well as to the admirable writ-

ings of Professors Thompson, Ayrton, and Perry, Messrs. Cumming, Prescott, and many others. I am indebted also to Messrs. Edison and Weston and the *Electrical World* for valuable cuts, and to Mr. S. D. Mott for kind assistance in preparing the illustrations.

BUREAU OF ORDNANCE, NAVY DEPARTMENT,
Washington, D. C., Oct. 2, 1883.

NOTE.

IT will be observed that the percentages, 85 per cent. and 80 per cent., given in the sixteenth and eighteenth chapters, do not indicate the real efficiency of a motor, but merely the ratio of the mechanical power given out to C'E'. The real efficiency is, of course, the ratio of the mechanical power given out to C' multiplied by the difference of potential between the brushes.

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ELECTRICITY

IN

THEORY AND PRACTICE.

CHAPTER I.

MAGNETISM.

IT is through the medium of magnetism that the principal applications of electricity are made in the arts; but magnetism may exist unaccompanied by any electrical manifestations.

The Lodestone.—The simplest form of magnet is the lodestone, or natural magnet, which is an ore of iron of the chemical formula Fe_3O_4. It is found in considerable quantities in many parts of the world, though not in quantities sufficiently great to render the lodestone of much practical use, were it not for its power of imparting its magnetism to steel (Fig. 1).

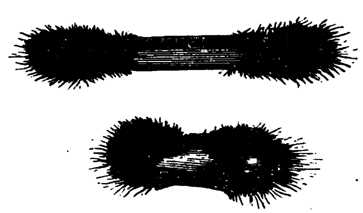


Fig. 1

Artificial Magnets.—If a lodestone be rubbed upon a piece of steel the latter will be found to have acquired

the peculiar properties of the former, as evidenced by its power of attracting iron, steel, nickel, cobalt, etc. It will also be found capable of imparting the same magnetic properties to other pieces of steel.

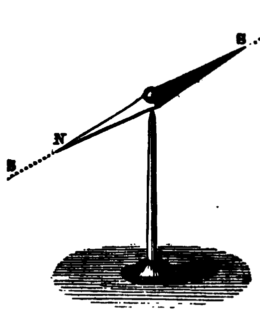


Fig. 2.

Poles of Magnets.—If a lodestone, or a piece of magnetized steel, be suspended so as to be free to turn (Fig. 2), it will point nearly north and south; and if it be dipped into iron-filings it will be noticed that these accumulate about each end (Fig. 3), showing that the magnetism is not distributed uniformly over a magnet, but is stronger at the two extremities. These two extremities are called the *poles*.

North and South Seeking Poles.—To investigate the action of the poles it is convenient to make a light needle of steel, rub it upon a lodestone or natural magnet to give it magnetic properties, and then mount it upon a vertical pivot, so that it can freely turn. The needle will now point nearly north and south. That pointing north is called the north pole, and that pointing south is called the south pole; though it is more accurate, as will be presently pointed out, to describe them as north and south seeking poles respectively.

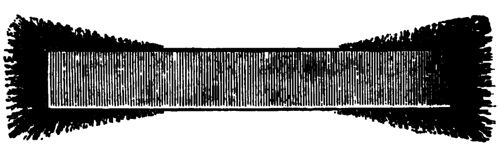


Fig. 3.

Magnetic Attraction and Repulsion (Fig. 4).—If we now take a similar needle, and bring up its north pole towards the north pole of our pivoted needle, the latter will be instantly repelled; while if we bring up a south pole it will be attracted. Or if we bring up a

south pole to the south pole of the needle, the latter will be repelled; while if we bring up a north pole it will be attracted. Thus we see that like poles repel each other, and unlike poles attract each other.

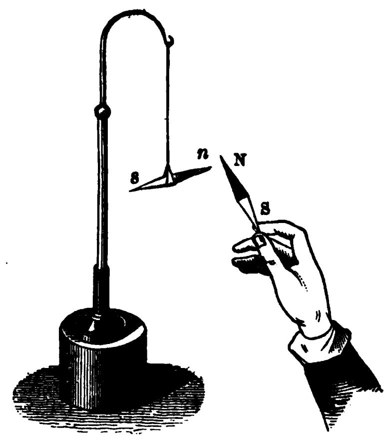


Fig. 4.

The Earth a Large Magnet.—The fact that each pole of a magnet is attracted towards one pole of the earth and repelled from the other has led to the hypothesis that the earth is itself a large magnet, of which one pole is near the geographical north pole, while the other is near the geographical south pole. As the north magnetic pole of the earth attracts the so-called north pole of the magnetic needle, it is clear that they must be unlike poles. Therefore, as has been said above, it is more strictly accurate, though not customary, to speak of the *north and south seeking* poles of a magnet.

Magnetic Substances.—A magnetic substance is one capable of being magnetized. The principal magnetic substances are iron, steel, nickel, cobalt, chromium, cerium, and manganese. A distinction between magnets and magnetic substances will be found in the fact that a magnetic substance will attract either pole of a magnet, no matter what part of the substance we present, while a magnet will attract only at its pole, and will attract only the unlike pole of a magnet.

Methods of Imparting Magnetism.—Magnetic substances may be magnetized in a variety of ways. If we simply rub them from end to end upon a magnet or lodestone, the point which last touched the magnet will be a

pole, and will be of the name opposite to that of the pole last touched. A convenient way to magnetize two pieces of steel at once is to hold them down upon the middle line of a magnet, and draw them apart towards the opposite poles of the magnet (Fig. 5). Another way of imparting magnetism is by utilizing the magnetism of the earth. This can be done by holding a steel rod in the magnetic meridian and subjecting it to vibrations by striking it or using other similar means, or by subjecting it to torsion while in that position. Still another way is to place hot bars of steel lengthwise between the poles of powerful magnets and allow them to slowly cool.

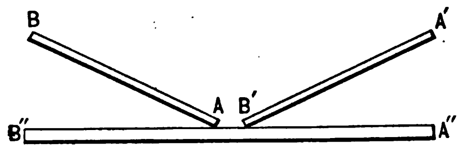


Fig. 5.

X **Point of Saturation.**—In no way can a piece of steel or any other magnetic substance be magnetized beyond a certain point. This point is termed the "point of saturation," and varies with different substances. Soft iron has a much higher point of saturation than steel, though it retains its magnetism only during the continuance of the magnetizing force.

Coercive Force.—The ability of a substance to retain magnetism is called its "coercive force." A substance with a great coercive force resists the escape of magnetism, but it also resists magnetization; while a substance with a small coercive force, like soft iron, is easily magnetized and as easily demagnetized.

X **Electro-Magnets.**—The usual way of magnetizing soft iron is to pass currents of electricity around it (Fig. 6). A magnet thus made, called a temporary or electro-magnet, exhibits all the properties of permanent or steel magnets while the current is passing, but becomes inert

instantly when the current ceases. A bar of steel may be magnetized by the same means; but, by reason of its high coercive force, it will retain most of the magnetism produced, and become a permanent magnet.

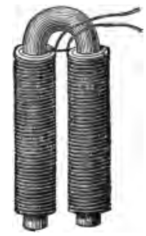


Fig. 6.

Magnetic Induction.—An easy way of producing magnetism in a piece of iron is to place it in proximity with a magnet-pole (Fig. 7). If we do this we shall find that the piece of iron becomes a magnet, and that the end near the magnetizing pole has the opposite polarity, while the farther end has the same polarity. Magnetism imparted in this way is said to be *induced*, and

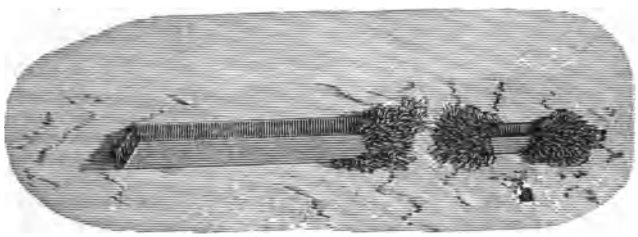


Fig. 7.

it can be so imparted to magnetic substances only; to some more than to others. Those magnetic substances capable of being magnetized to a high degree are said to have a high "coefficient of magnetization."

The phenomenon of induction explains the attraction of a magnet-pole upon soft iron. It first induces in the iron two poles, an unlike pole at the near end and a like pole at the farther end. For the unlike pole it exerts an attraction, and for the like pole a repulsion, and, the former being the nearer, the force of attraction overcomes the force of repulsion.

Strength of a Magnet-Pole.—By this expression is meant the power of a pole upon a magnetic substance. It is not the same as its lifting power, because this de-

pends upon the shape of the magnet and a variety of external conditions. The usual way of measuring the strength of a magnet-pole is to measure its repelling power upon a similar and equal pole, expressed in terms of unit magnetic strength. A pole of unit strength, or a unit magnet-pole, is one which, if placed at unit distance (one centimetre) from a similar and equal pole, will repel it with unit force (one dyne). A dyne is about $\frac{1}{981}$ gramme.

Measurement of Magnetic Force.—This is usually accomplished by the torsion-balance (Fig. 8). In this instrument a small bar-magnet is hung without torsion by a fine thread inside of a cylindrical glass jar, around whose circumference a graduated scale is marked. The top is covered by a circular cap (*c*), which can be revolved, the number of degrees through which it is revolved being shown by a second graduated scale. From the centre of this circular cap hangs the thread which holds the magnetic bar or needle. The needle being placed in the meridian, an experiment is first made to see how much twist or torsion of the wire is needed to deflect the magnet one degree from

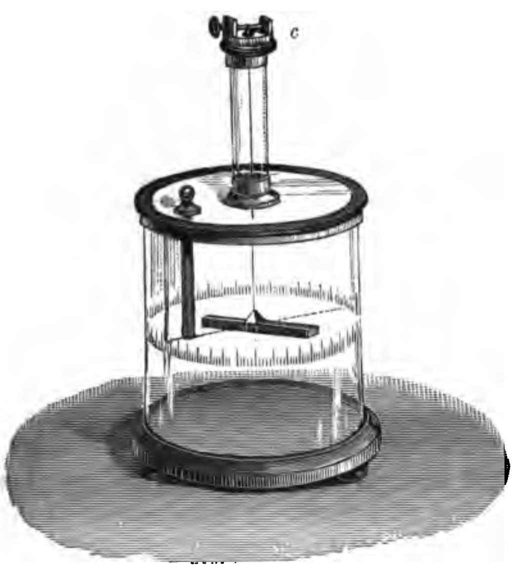


Fig. 8.

the meridian; this being ascertained, the circular cap is turned back until the magnet again lies in the meridian. A magnet-pole is now introduced through a hole in the top of the jar, and placed near the like pole of the suspended magnet. The latter will be, of course, repelled through a certain number of degrees, as shown by the scale on the side of the jar. This number of degrees multiplied by the number of degrees of torsion of the thread which we found were needed to deflect it through one degree, is equal to the torsion which would be required to produce the same deflection. If now we revolve the cap backwards until we halve the deflection of the needle, we shall find that the amount of torsion which we thus subject the wire to will be four times the amount of torsion we have just computed; or if we reduce the deflection to one-third, we shall find that a torsion of nine times that amount is necessary. But as in twisting any wire or thread the angle of torsion is proportional to the force of torsion, we see that the repulsive force at a distance of one-half is four times as great as that at a distance of one, and that the repulsive force at a distance of one-third is nine times as great. In other words, the repulsive force of a magnet is inversely as the square of the distance.

Method of Oscillations.—Another method of measuring magnetic force is the method of oscillations. A magnet set to oscillating, when under the influence of a magnetic force, acts like a pendulum when oscillating under the influence of the force of gravity; so that the square of the number of oscillations performed in a given time by a magnetic needle is proportional to the magnetic force. In this way we can compare the strength of the earth's magnetism in two places by comparing the number of oscillations per minute of the same magnet in each of the two places. This method is sometimes used also in comparing the relative strength of two magnetic poles,

by setting a little magnet to oscillating under the influence of one and then of the other, being careful, of course, to keep it at the same distance in both cases. We can also use this method to get the comparative strength of different parts of the same magnet, by setting a magnetic needle to oscillating opposite those different parts; the square of the number of oscillations executed in a given time opposite to those parts being proportional to the strength at those parts.

Broken Magnets.—If a magnet be broken into any number of parts, each part will be a complete magnet

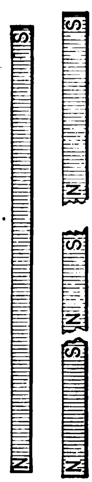


Fig. 9.

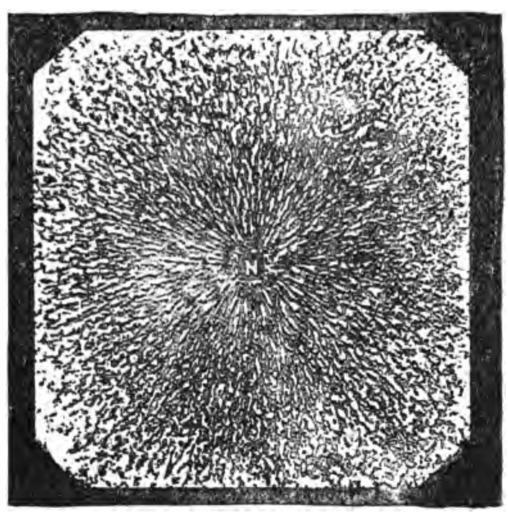


Fig. 10.

in itself, having a pole at each end (Fig. 9). If, however, these parts be joined together again, like poles will come opposite each other and neutralize each other, so that we will have but one complete magnet as before.

Lines of Force.—The study of the action of magnetic poles can be greatly facilitated by assuming that

magnetic force acts in straight lines radiating from each pole. That this is not a baseless assumption may be easily proved by sifting upon a sheet of glass a number

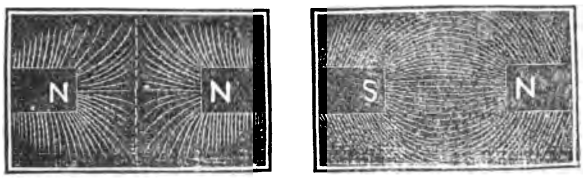


Fig. 11.

of very fine iron-filings, and placing directly beneath one or more magnet-poles. On now lightly tapping the glass to overcome the inertia of the filings they will be seen to set themselves along definite lines, which vary with the number and kinds of poles beneath. If but one pole is used the filings will radiate in all directions from a point immediately above this magnet-pole (Fig. 10). If two like poles are used they will form in two different systems, the lines of each system radiating from a point above one of the poles, and seeming to be repelled from the lines of the other system (Fig. 11). If, on the other hand, two unlike poles are used, the lines

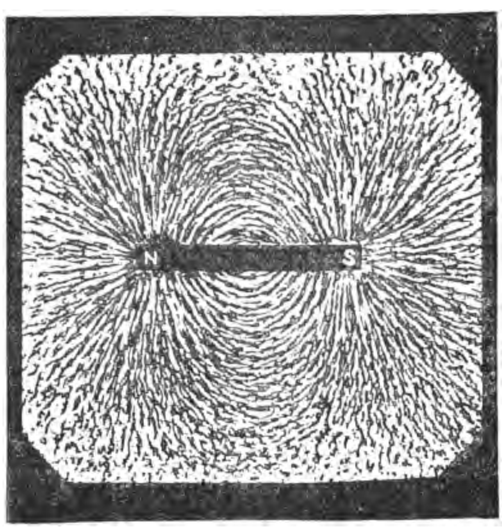


Fig. 12.

of each system will seem to be attracted by the other system, and show a tendency to run together; so that while in the first case the lines were bent into curves bending away from the opposite pole, these are bent into curves which bend towards the opposite pole. This will be the case whether the two dissimilar poles belong to the same magnet or to different magnets. If we place beneath the glass a single bar-magnet, so that it lies parallel to the glass, the lines will curve over from one pole to the other (Fig. 12). In case this bar-magnet has a number of "consequent poles"—that is, extra poles produced along its length, either by touching it with a

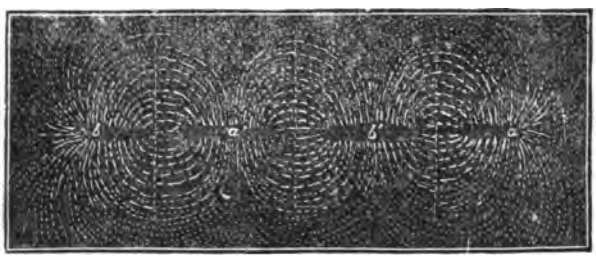


Fig. 13.

magnet at different points, or, in the case of an electro-magnet, produced by the method of winding the coils of wire—the filings will be attracted by these consequent poles, and will form in lines like those shown in Fig. 13.

Magnetic Field.—We thus see that the air surrounding the pole of every magnet is traversed by magnetic forces which act in straight lines,* and that these lines extend to a considerable distance. The vicinity of a magnet traversed by these lines of force is called a "magnetic field"; and when a body is placed under the influence of a magnet-pole we say that it lies in a magnetic field due to that magnet-pole. The magnetic field at any point is strong or weak according to the strength and distance of the magnet-pole.

* The direction of the force at any point is the tangent of the curve at that point.

Comparative Strength of Magnetic Attraction and Repulsion.—Magnetic repulsion is not so strong in practice as magnetic attraction, for the reason that, when two similar poles are brought near each other. each endeavors to develop in the other a pole dissimilar to itself. For this dissimilar pole it will exert a certain attraction, which must be subtracted from its repelling force. In case one very strong magnet-pole is brought very near to a similar very weak one, its inductive effect may be so great that it will overwhelm the original magnetism of the weak pole, induce a contrary polarity, and consequently attract it. In the case of two dissimilar poles, however, the mutual inductive effect increases the original attraction. The harder the steel the less does the disturbing influence of induction affect the attraction and repulsion of the magnets. In order, however, to apply the law of inverse squares without error, the distance must be so great that there is no danger of induction.

The Compass (Fig. 14).—This consists of a magnetic needle carefully mounted and pivoted, which, in obedience to the attracting and repelling force of the earth's magnetic poles, sets itself along the line joining them. As these magnetic poles are not exactly at the geographical north and south poles, the magnetic meridian in which the needle lies does not exactly coincide with the geographical meridian. The angle which the magnetic meridian

Fig. 14.

at any place makes with the geographical, or true, meridian is the "variation of the compass" at that place. As usually constructed the compass-needle is attached to a card which is supported upon a vertical pivot in a basin filled with alcohol and hermetically sealed, the basin being supported upon gimbals to allow of free motion in every direction.

Dip.—If the needle is supported upon a horizontal pivot which lies in a frame that can be revolved about a vertical axis, it will assume a position inclined to the horizontal (Fig. 15). When the frame is revolved so as to bring the needle into the magnetic meridian, the angle which the needle assumes is at its minimum, and is called the "dip," or "inclination." The cause of this inclination will become evident if we remember that the direction in which the poles of the earth lie is not parallel to the surface at any point, and that the angle which the needle makes with the horizon shows the direction in which the nearest magnetic pole lies. The angle of dip is evidently at its minimum at the magnetic equator, which is approximately the geographical equator; so that we can say in general terms that the inclination increases with the latitude.

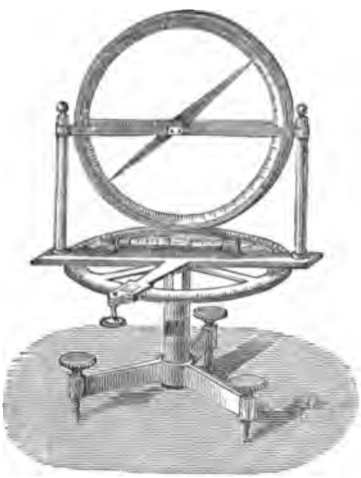


Fig. 15.

CHAPTER II.

FRICTIONAL ELECTRICITY.

THE simplest way of producing an electrical condition in a body is to rub it with a dissimilar substance. Any two substances when rubbed together exhibit evidences of electrification; but those exhibiting them in the most marked degree are fur, wool, ivory, glass, silk, metals, sulphur, india-rubber, gutta-percha, resinous substances, wax, and amber.

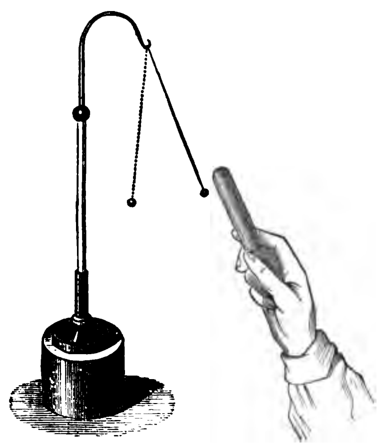


Fig. 16.

Electrical Attraction and Repulsion (Fig. 16).—If we rub a glass rod with a piece of fur, and hold it out near a little pith-ball which hangs by a silk thread, the latter will be instantly attracted. If, however, the pith-ball be allowed to touch the glass rod, it will cling to it for an instant, and then dart away.

If we hang a piece of glass which has been rubbed with silk by a silk thread, and bring up near it a glass rod which has also been rubbed with silk, repulsion will instantly ensue; while if we bring up a piece of sealing-wax which has been rubbed with fur attraction will ensue. But if we suspend a piece of sealing-wax which has been

rubbed with fur, and bring up near it another piece of sealing-wax which has also been rubbed with fur, the suspended wax will be repelled. If, also, two pith-balls are both touched by the same electrified substance they will repel each other (Fig. 17).

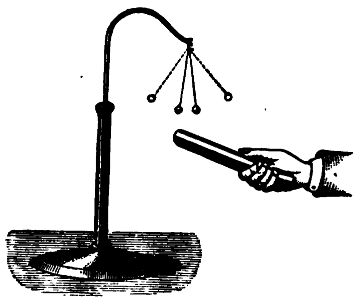


Fig. 17.

Negative and Positive Electricity.—The study of these phenomena leads us to the conclusion that there are two different kinds of electrification; while the fact that similar bodies which have been rubbed with the same substances repel each other leads us also to the conclusion that the repulsion is due to the fact that they are similarly electrified. Although we have no evidence that such a thing as electricity absolutely exists, yet it is customary to adopt the hypothesis that this peculiar state in any body is due to the presence therein of electricity; and as we have seen that this electricity manifests itself in two opposite ways, the hypothesis is adopted that there are two kinds of electricity. To that kind of electricity produced on glass by rubbing it with silk the term *positive* is applied, and to that kind produced on resin by rubbing it with fur the term *negative* is applied. From the experiments conducted above we infer that *like electricities repel each other, and that unlike electricities attract each other.*

Both Positive and Negative Electricity Produced at the same Time.—If we hang a piece of glass by a silk thread, and rub it with a piece of fur mounted upon a glass rod, the glass and fur will be found to be oppositely electrified and to attract each other. If, also, after rubbing a glass rod with a piece of silk, we touch it to a light pith-ball, so as to communicate a por-

tion of the electricity to the pith-ball, and if we then bring up the piece of silk, the pith-ball will be at once attracted by it. Thus we see that when two dissimilar bodies are rubbed together one assumes one kind of electrification, the other the other. In the following list the arrangement is such that, if we rub any two of them together, the one which stands the nearer to the head of the list will be positively electrified, the latter negatively: cat's skin, wool, ivory, glass, cotton, silk, wood, metals, caoutchouc, sealing-wax, resin, leather coated with amalgam. If two similar substances of different textures, degrees of polish or temperature, be rubbed together, one will be positively electrified, the other negatively. Generally speaking, that body whose particles are the more readily disengaged will be negatively electrified.

Charge.—Not only may bodies be charged with different kinds of electricity; they may be charged to different degrees and with different amounts of electricity. In case a body is charged with a large amount of electricity it is said to have a large "charge"; while if it is charged with a small amount it is said to have a small "charge." When the charge is removed the body is said to be "discharged."

Conductors and Insulators.—If we rub some bodies, such as the metals, and hold them in the hand while so doing, we shall not be able to discover any manifestation of an electrical state. But if we mount the body upon a glass rod (Fig. 18), and hold this glass rod in the hand, the body will then, after being rubbed, exhibit all the evidences of electrification. The reason is that some bodies, notably metals, allow electricity to pass through them with such ease that, in the case above mentioned, the electricity passed off into the hand, and thence into the ground, as fast as it was produced. Glass, however, op-

Fig. 18.

poses very great resistance to the passage of electricity; so that when we rub a piece of metal mounted on glass most of the electricity produced on it is confined. It was for this reason that, when we desired to obtain evidence that electricity is produced in the body rubbing as well as in that rubbed, we mounted upon a glass rod the fur with which we were to rub the other glass rod. Those substances which allow electricity to flow freely through them are called "conductors," while those which resist strongly the passage of electricity are called "non-conductors" or "insulators." In the following list the substances named are arranged in the order of their conducting power; no substance, however, is so perfect a conductor that it does not resist to some extent the passage of electricity, and no substance is so perfect an insulator that it will not allow some electricity to leak through it: silver, copper, other metals, charcoal, graphite, water, the body, linen, cotton, dry paper, porcelain, resin, gutta-percha, amber, shellac, paraffine, glass, dry air.

Quantitative Laws of Attraction and Repulsion.—1. The repulsion or attraction between two electrified bodies is inversely as the square of the distance between them.

Fig. 19.

2. The distance remaining the same, the force of attraction or repulsion between two electrified bodies is directly as the product of the quantities of electricity with which they are charged.

The experimental proof of these laws is easily shown by the torsion-balance. The arrangement is much the same as when used to determine the laws of magnetic attraction and repulsion. A fine shellac thread with a gilt ball at its

end replaces the magnetic needle, however, and a glass rod with a gilded pith-ball at its lower end replaces the magnet whose force was to be measured (Fig. 19). The cap at the top is turned to zero, and the tube is revolved until the pith-ball also points to zero on the graduated scale on the side. The knob *m* is now removed, electrified, and introduced into the jar. When it reaches its seat it touches *n*, communicates to it some of its charge, and therefore repels it through a certain number of degrees. In order to reduce the deflection to one-half of its present value the cap is revolved backwards; and it will be found that when the deflection has been halved the torsion in the wire will be four times as great as it was before; if the deflection be reduced to one-third the torsion will be nine times as great. The angle of torsion being proportional to the force of torsion, the experiment proves that the repulsive force varies inversely as the square of the distance.

To prove the law of attraction the method of procedure is the same, except that the two balls are oppositely charged, and that they are prevented from moving together by the torsion of the wire. It is found that four times as much torsion in the wire is needed to overcome the mutual attraction when they are one centimetre apart as when they are two centimetres apart.

To prove the second law let any charge be imparted to *m*. On touching *n* some of its charge will be communicated, and a certain repulsion will ensue. Now let *m* be touched with a similar and equal ball, so that it will lose half its charge; then the distance of repulsion will instantly be reduced to one-half.

Unit of Electricity.—A unit of electricity is that quantity which, when placed at a distance of one centimetre from a similar and equal quantity, repels it with a force of one dyne.

Electric Induction.—If we bring a positively-elec-

trified glass rod near an oblong piece of metal mounted upon a glass standard (Fig. 20), we shall find that the metal is electrified, though it has not been touched. Pith-balls mounted at the ends will stand out with the force of electrical repulsion, but a pith-ball placed midway between will exhibit no such signs of electrification. A further examination will show that the pith-balls are oppositely electrified, and that the one near the glass rod is negatively electrified, while the one at the farther end is positively electrified. If we now remove the glass rod both pith-balls will drop and all signs of electrification will vanish from the conductor, the two opposite electricities recombining. Electricity thus generated is said to be " induced " ; electricity of the opposite name being induced upon the adjacent side of a conductor, and electricity of the same name being repelled to the farther end.

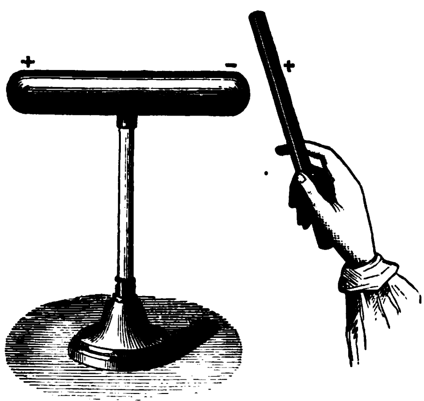


Fig. 20.

If the conductor is made in two halves which can be separated, and then, while the inducing body is present, they are drawn asunder, the electricity residing on each will remain upon it, even if the inducing body be now removed. But if, after its removal, the two halves be again joined, the two electricities will recombine.

If the farther end of the conductor be connected by a conducting medium with the earth, only that end near the inducing body will show signs of electrification, for the reason that the electricity which was repelled to the other

end has passed into the earth. The electricity induced upon the near end is held, or "bound," by the inducing charge. If now the connection with the earth be broken, and the inducing charge removed, the induced electricity, being free to move, will distribute itself over the whole surface of the conductor, which will, therefore, be electrified throughout with electricity of the opposite kind from that on the inducing body.

As in the case of communicating a charge by touch, the charge induced varies not only in kind but in degree; for a highly electrified body wili induce a greater amount of electricity than one feebly electrified. If the two insulated bodies come nearer and nearer together the induced charge at each end will become greater and greater, and the mutual attraction which the adjacent charges exert on each other in their effort to recombine will produce a stress upon the intervening air. Finally a point will be reached at which the mutual attraction will overcome the resistance of the air, and the opposite electricities recombine with a spark and a sharp detonation, leaving upon the insulated conductor a permanent charge of the same name as that of the inducing body.

Cause of Attraction.—The phenomenon of induction explains the cause of electrical attraction. In the case of a positive charge approaching a pith-ball, it induces on the near side of the ball a negative charge, and on the distant side a positive one. For the former it has an attraction, for the latter a repulsion; but as the former is the nearer, the attracting force overcomes the repelling force (Fig. 21). As soon as the pith-ball touches the positively-charged body, however, its feeble charge of negative electricity recombines with a similar amount of positive electricity, leaving the pith-ball positively charged, so that it is instantly repelled again.

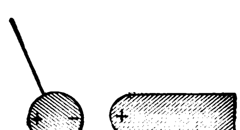


Fig. 21.

Inductive Capacity.—The effect of induction is modified by the nature of the medium across which it acts. If paraffine, oil, or solid sulphur be this medium the inductive action will be much stronger than if it be air. The power of any substance to allow inductive action to take place across it is called its inductive capacity. The substance across which the inductive action acts is called a "dielectric."

Electricity resides upon the Surface.—A peculiar property of electricity is that it resides only upon the surface of bodies. This can be easily shown by charging a hollow metal ball mounted upon a glass standard. If we touch to the outside of this ball (Fig. 22) a gilt disc mounted upon a glass rod (called a "proof-plane"), and if we then bring this proof-plane near a pith-ball, attraction will instantly ensue. But if we put the proof-plane inside of the metal ball, and even touch its interior surface, it will acquire no electrical charge whatever.

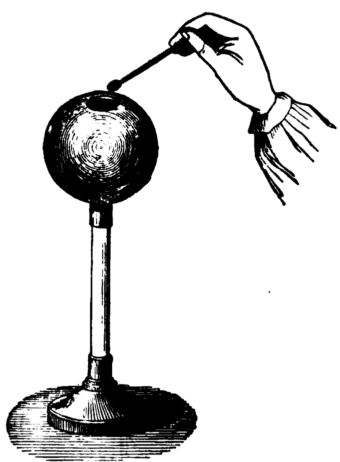


Fig. 22.

Electric Density.—Another peculiarity of electricity is its tendency to accumulate upon points and edges. The way in which electricity distributes itself over bodies of peculiar shapes may be seen from Fig. 23, in which the dotted lines indicate, by their distance from the surface of the body, the amount of electricity at different points. The "electric density" at a point is the number of units of electricity per unit of area, the distribution being supposed to be uniform over that area.

Leyden Jars, or Condensers.—The Leyden jar is an important application of the principle of induction. We have found that a body charged with positive electricity will induce a negative charge upon the adjacent side of a body near at hand, and that the degree of inductive effect depends upon the nature of the intervening medium, or dielectric. Suppose now that we take a sheet of glass, and paste upon opposite sides two pieces of tinfoil that do not extend to the edges of the glass. On now connecting one piece of foil with a positively-charged body, and connecting the other piece with the earth, the plus electricity conducted to the former piece will induce

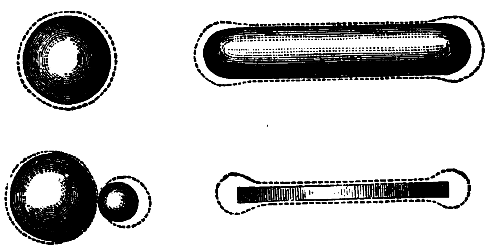


Fig. 23.

negative electricity upon the latter piece, and repel positive electricity into the ground. The induced negative charge will induce a certain amount of positive electricity upon the positive piece, thus calling for a greater supply from the source of electricity. The positive charge being now increased, a greater negative charge will be induced on the negative sheet of foil. The thinner the glass the more readily can the inductive action go on, and the larger the pieces of foil the greater charge can they receive and induce. The glass then, by its inductive capacity, allows the pieces of foil to accumulate or condense a much greater quantity of electricity than they could of themselves take up. If we now remove the connections from the negative foil to the earth, and from the

positive foil to the source of electricity, both charges will be "bound" upon the sheets of foil.

In the Leyden jar (Fig. 24) the glass is made in the form of a jar, and the two sheets of foil form outside and inside coatings. A brass knob is fitted in the top, which is made of wood or other suitable material, and it communicates with the interior lining of foil by means of a metal chain. The outer coating is connected to the earth by standing the jar upon a table or other convenient support. If now the brass knob be connected with an electrical machine, or other source of electricity, the two sheets of foil react upon each other in the manner described above; so that when we finally break connection with the machine our jar will be found to have accumulated a considerable amount of electricity. If the jar be dry, free from dust, and of good glass, it will retain its charge many hours; but if a conducting path be furnished, whereby the two charges can recombine, they will do so instantaneously. The usual device for discharging a Leyden jar is a pair of "discharging-tongs," such as shown in Fig. 25. The arms themselves are metallic, but the handle is made of glass, in order that the charge may not flow through them into the body of the operator. If now we touch the outside coating with one arm, and the knob with the other, a sharp detonation and a spark will announce the recombination of the two charges. Or if we grasp the outside coating with one hand, and touch the knob with the other, the body will take the place of the discharging-tongs, a spark will pass between the hand and the knob, and a shock will be felt over the body.

Fig. 24

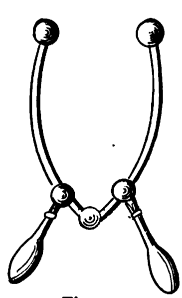


Fig. 25.

Electrical Machines.—These are mechanical devices for generating larger quantities of electricity than can be obtained by the means thus far described, of rubbing glass rods, etc. Numerous machines have been devised for rubbing together by convenient means large surfaces of suitable substances, the amount of charge evoked depending upon the extent of surfaces rubbed, the amount of friction, and the distance from each other of the surfaces rubbed together, in the scale of electrification given above, the greatest effect being produced by the friction of those substances farthest apart in the list.

The Plate Electrical Machine.—As will be seen from Fig. 26, this consists of a circular plate of glass, capable of being revolved by a handle, between two pairs of rubbers, F. These rubbers are made of leather covered with an amalgam of zinc and tin, so that the friction produced by revolving the plate between them produces upon the glass a strong positive charge (see list). Now around the plate is bent a metallic conductor, mounted upon insulated supports, and furnished with sharp spikes which project towards the glass plate, but do not touch it. When, in the course of its revolution, the glass plate brings its positive charge opposite to these points, a negative charge is induced upon them of such high tension and density that they cannot retain it, so that it recombines with the positive charge on the glass. This has two effects: first, the positive charge on the plate opposite the points is neutralized, so that the plate is taken around to the rubbers in a passive condition and ready to receive a new charge; second, the negative charge induced upon the metallic conductor being withdrawn, a charge of positive electricity is left upon it. By continuously revolving the plate this positive charge is increased, so that ultimately a large amount is accumulated. The conductor is usually termed the "prime conductor" of the machine. In order to prevent the electricity upon

the plate from escaping into the air, flaps of silk are placed over it between the rubbers and the points. The negative charge produced upon the rubbers is allowed to flow off into the earth by connecting the rubbers to earth with a chain.

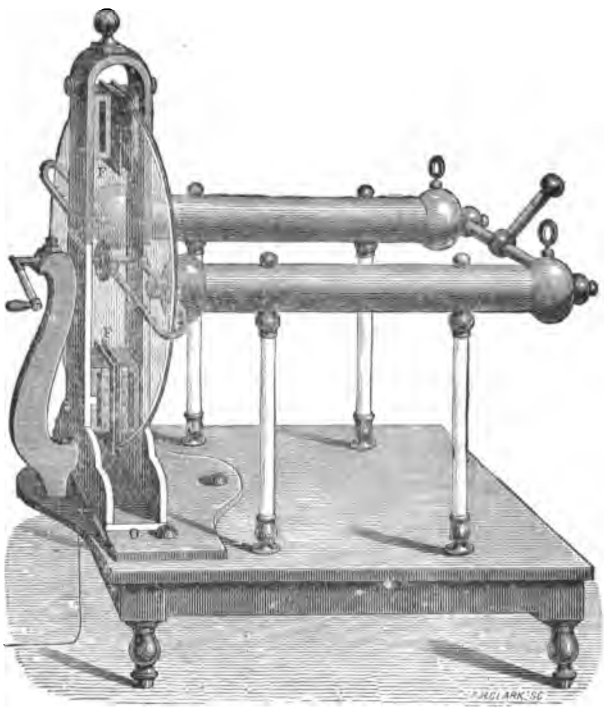


Fig 26.

The Holtz Machine.—The machine most used in generating frictional electricity is that of Holtz (Fig. 27). In this two plates of glass lie parallel to each other, one being fixed, the other capable of being revolved by means of a handle and accelerating gearing or belts. The fixed plate has two small windows cut in it, and near each win-

dow, on the side opposite the rotating glass plate (we will call this the rear side), is affixed a piece of stiff varnished paper, called an "armature." Both armatures are prolonged into long tongues, which reach into the window and are bent around until they almost touch the rear side of the revolving plate. These tongues point in the direction opposite to that in which the plate revolves. At the front of the machine are two conductors terminating

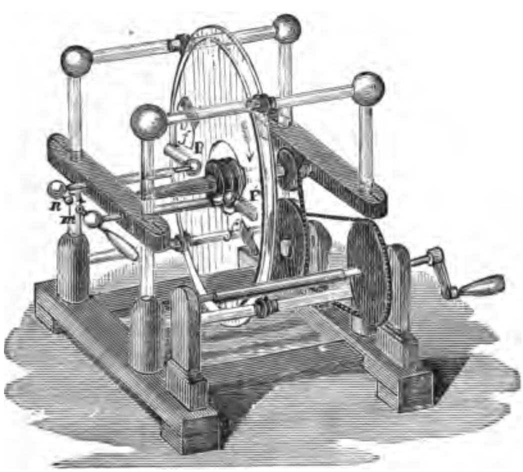


Fig. 27.

in knobs, *m* and *n*. These conductors slide in bearings, so that they can be drawn apart and pushed together again. They communicate each with one of two combs or brushes with metallic points, P and P′, which lie opposite the two armatures, *f* and *f*′, though, of course, separated from them by the thickness of the revolving plate. The action is as follows: The knobs, *m* and *n*, being placed in contact, and a small positive charge being communicated to one of the armatures, say to *f*′, the glass plate is given a rapid revolution. The plus charge immediately acts inductively upon the metallic comb P′ through the glass.

This attracts negative electricity to the points, which is instantly discharged upon the front surface of the revolving plate, while plus electricity is repelled through the metal knobs, and thence to the left comb, P, where it is discharged upon the front side of the revolving plate opposite the points. Here it acts by induction upon the left paper armature, *f*, attracting negative electricity and repelling positive into the tongue of said left armature, which slowly discharges it upon the rear side of the rotating plate. The revolution continuing, this charge on the back comes around until it gets opposite the right comb, P′. Upon this it acts by induction, attracting a minus charge to the points, which discharges itself on the front surface of the plate, and repelling a plus charge through the rods and metal knobs and into the left comb, P. Thus it assists and increases the action of the armature first charged. But the minus charge which we saw produced in the left armature by the positive electricity of the left comb has meanwhile attracted more positive electricity into this comb, and therefore has increased its discharge of positive electricity upon the front surface of the revolving plate. It has also repelled minus electricity through the brass rods and knobs and into the right comb, P′, which discharges also upon the front surface of the plate. This minus electricity neutralizes the plus charge brought around from the left brush by the front surface; so that during one-half of the revolution (in this case in the upper half) both sides of the disc are positively electrified, while in the other half both sides are negatively electrified.

When the armatures and combs have reacted upon each other until a considerable charge has been produced (which will be shown by the resistance offered to the turning of the crank, and by a light blue flame issuing from the points) the knobs are drawn apart. The current passing between them will now have reached such a tension

that it can overcome the resistance of the intervening air, and it will jump across it, producing a brilliant succession of sparks.

Other Methods of Producing Electricity.—Besides friction there are numerous other sources of electricity; among these are percussion, vibration, disruption and cleavage, evaporation, pressure, combustion, the application of heat and cold to certain crystals, heating the junction of dissimilar metals, and placing in contact dissimilar metals. None of these, however, except the two last named, have ever been used in practice.

Atmospheric Electricity.—Many atmospheric phenomena are believed to be due to the electricity developed by the evaporation of the water on the globe. The clouds, being charged with one kind of electricity, hang over the earth, which is oppositely charged, while the intervening air acts like the glass of a Leyden jar and keeps the opposite electricities from recombining. If, however, the tension becomes so great as to overcome the resistance thus offered, the opposite charges come together with a flash and a detonation, producing the well-known phenomena of thunder and lightning. The charge on the lower side of the cloud is thus neutralized, but the other portions still contain charged surfaces. The equilibrium being now destroyed, however, internal combinations and reactions are set up, giving rise to rumblings, flashes, and detonations.

CHAPTER III.

WORK AND POTENTIAL.

In order to apply electricity to the practical uses of supplying light and power, it is necessary to study its action quantitatively as well as qualitatively: not only must we know that we can do certain things by its means, we must also know how much expenditure of time and money it will cost. To arrive at this knowledge it becomes needful to study the performance of work, because in the commercial world it is by this standard that all estimates are made and all expenses calculated.

Work, it is well known, is the product of force by distance. When we lift a weight from the ground we overcome the force of gravity, which tends to keep together the two attracting bodies, the weight and the earth. To lift one pound we have to exert a certain amount of strength; that is, we have to do some work. Now, as the force of attraction between the earth and a two-pound weight is twice that between the earth and a one-pound weight, it is obvious that we should have to do twice as much work to lift two pounds one foot as one pound. But suppose that, instead of raising two pounds one foot, we raise it two feet. It clearly will require just as much work to raise it the second foot as it did the first; so that the work of raising it two feet will be twice that of raising it one foot. As we have found that it requires twice as much work to raise two pounds one foot as to raise one pound through the same distance, it clearly requires four times as much work to raise two pounds through a dis-

tance of two feet as to raise one pound through a distance of one foot. The same reasoning will show that it takes one hundred times as much work to raise ten pounds ten feet as to raise one pound one foot. Now, the work of raising one pound one foot is called "a foot-pound," and is the unit ordinarily used in the United States and Great Britain. This unit is, however, too large for measuring with convenience in many cases; and for this reason a much smaller one has been invented, called the "erg." It expresses the work performed in lifting a weight of one dyne through one centimetre. A dyne is an extremely minute weight, being about $\frac{1}{981}$ of a gramme. A gramme is about .0022 of a pound, and a centimetre is .39 inch.

We have already seen that magnet-poles and electrified bodies exert forces of attraction and repulsion upon other magnet-poles and electrified bodies. The force thus exerted can be measured just as easily as that of a weight can, for the force a weight exerts is merely by reason of the attraction between it and the earth; and it can also be expressed in terms of the same unit, the dyne.

But for the same reason that a mere statement of the weight a body has conveys no idea of the amount of work it can perform, unless we state how high it has been raised, so a statement of the magnetic or electric force a body can exert conveys no idea of what work it can perform, unless we know through what distance it be exerted. It therefore becomes necessary to adopt some expression which will show not only how much force a magnet-pole or electrified body can exert, but also how much work it can do. The expression used to convey this idea in electrical science is "potential."

Electric Potential.—We have seen that an electrified body exerts a repelling force upon a body similarly electrified. To forcibly bring up, then, such a body against the opposing force will clearly require the expenditure of a certain amount of work, which will be

greater the more highly electrified both bodies are, and the greater the distance through which the repulsion is overcome. In order, therefore, to get an expression of unit work or unit potential, it will be necessary to bring up a unit charge. As the repelling power of the stationary charge has a certain value, mathematically speaking, over even immense distances, we shall have to start the unit charge from a point infinitely distant, so as to be free from its influence. Now, in bringing it up against the repelling force it is clear that at first this force is not appreciable, but that it grows stronger and stronger as the intervening distance grows smaller. It would not be accurate, then, to say that after we had moved it over any distance, such as a centimetre, we had performed an erg of work, because the force has been far from constant and has been very small. Ultimately, however (supposing the fixed charge to be large enough), we shall have done one erg of work. The point at which we have now arrived is said to have a potential of one; that is, it has required one unit of work to bring up a unit charge of the same name as the repelling charge up to that point from an infinite distance. For the sake of uniformity positive charges are supposed to be used; a negative one would itself do work in going up to a positive charge, instead of requiring work to be done upon it.

If now we bring the plus unit charge closer and closer to the fixed charge, more work will have to be done. Eventually we shall get the unit charge close up to and touching the surface of the stationary one. The amount of work will, of course, vary with the repelling force of this charge—that is, with its amount. If the work required be two ergs, then the surface of the fixed stationary body which the unit charge touches will have a potential of two; if three ergs had to be expended, then its potential will be three.

The potential at any point is, then, the work that must be

done on a plus unit of electricity in getting it up to that point from an infinite distance.

The significance of potential will not be evident, however, until we reflect that when we raise a weight through a certain height, or a unit of electricity to a certain potential, the weight and the unit can do the same work in falling as was done in raising them. If we raise a pound a distance of one foot, thereby doing a foot-pound of work, we store up an energy, or potential, of one foot-pound, because if we let the weight fall it will itself perform one foot-pound of work. This work may be used for turning machinery or for other useful purposes; but in case it is not the weight will fall unimpeded to the ground, and will perform the same amount of work in indenting the earth and developing heat at the point of impact. In the same way, if we free a plus unit of electricity which we have raised to a potential of one, we shall find that we have stored up an amount of energy equal to the amount of work required to accomplish this; for in obeying the force of repulsion the plus unit will go off to an infinite distance, thereby performing one erg of work.

The fact that work has been done either in raising a weight or electrifying a body to a certain potential shows that there has been a forcible disturbance of equilibrium, which nature will restore at the first opportunity. The weight, then, will fall as soon as released, and the unit charge will also fall as soon as given a medium, or "conductor," through which it can fall. We have seen that electricity flows through some substances; the reason will now be plain, for we see that it is only endeavoring to expend energy by falling from a highly electrified place, or one possessing a high potential, to one of low potential; and that the conductor is merely a medium through which it can fall, in the same way that air is a medium through which a weight can fall.

The way of producing electricity by turning a friction-

al machine is, however, very unsatisfactory in practice; the degree of electrification, or potential, attained is extremely high, but the quantity of electricity produced is extremely minute. It is as though a very small amount of water fell from an immense height. In the arts a larger quantity is needed, and so high a potential is not ordinarily required; to carry out the water analogy, we need more water, but do not care to have so much "head," or force. A more convenient power is therefore required, and this we find in the voltaic, or galvanic, or, as it is sometimes called, hydro-electric, battery. This consists of two dissimilar substances, standing in one or more liquids, and connected by a wire. The contact of the metal wire and the dissimilar substance of the battery produces an opposite electrification, and therefore a difference of potential, in them. The higher potential, in seeking to fall to the lower through the conducting medium of the wire, sets up a "current" therein. This would speedily reduce the whole system to the same potential, were it not that chemical action begins in the battery, and this has the effect of restoring the high potential as fast as it falls, thus maintaining the difference of potential, in the same way that, in the frictional machine, the revolution of the glass disc maintains it. The result is a "current" of electricity flowing through the wire.

Electrification by Contact.—Volta discovered that when two different metals were placed in contact they became electrified, one positively, the other negatively. He also discovered that the degree of electrification, or the difference in potential, between them was greater when certain substances were used than others. A careful series of experiments with metals of all kinds showed which assumed the greatest difference of potential. He then arranged in a list the substances found to be most suitable, and placed them in such an order that, when any two are used, the one of them nearer to the head of the

list will be the one positively, the other the one negatively, electrified. The list as arranged by Volta was: zinc, lead, tin, iron, copper, silver, gold.

Since then sodium and magnesium, in the order named, have been found to be more positive than zinc, and platinum and carbon, in the order named, more negative than gold; so that the list now stands: sodium, magnesium, zinc, lead, tin, iron, copper, silver, gold, platinum, carbon.

It follows from the principle of the arrangement that the farther apart any two metals stand in the list, the greater will be the difference of potential between them when placed in contact, and therefore the more vigorously will the current circulate in the connecting wire from one to the other.

Sir William Thomson's Quadrant Electrometer.—This is an instrument represented in Fig. 28. It consists of a glass case, supporting a tube carrying a metallic thread, from which hangs a light needle to which a charge of electricity has been imparted, so that it will be attracted by a body dissimilarly charged, and repelled by one similarly charged, the degree of attraction or repulsion depending upon the charge of the needle and the other body. Below the needle are two pairs of quadrants, 1 3, and 2 4, the two opposite quadrants being connected with each other, and communicating with the bodies whose difference of potential is to be measured. If the

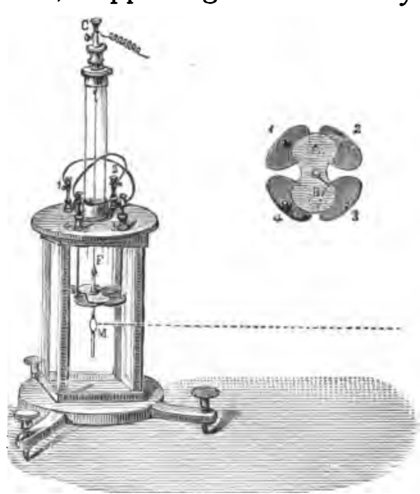


Fig. 28.

two poles of a battery or condenser, or if two points of a conductor traversed by an electric current, be connected to the two pairs of quadrants, the two pairs of quadrants will assume different potentials. As the quadrants are arranged it is clear that the two in each pair assist each other in turning the needle. As the two pairs are equal in size, the needle will remain unaffected, if they both be charged to the same potential; otherwise it will be attracted by one pair and repelled by the other, if they are charged with different potentials, or if both are similarly charged, though in a different degree, the effect of the pair of higher potential will overcome that of the lower. The needle is kept at a certain potential by being connected by a wire, *c*, with a charged condenser.

To amplify the linear graduation of the instrument a ray of light is made to fall upon a little concave mirror, M, hanging below the needle in such a way that the reflection is thrown upon a screen marked with a graduated scale, so that a slight movement of the needle will produce considerable movement of the reflected spot of light. The same device is also found in Sir William Thomson's mirror galvanometer. Behind the screen in each instrument is a light which shines, through a slit in the screen, upon the mirror. When the needle is in its normal position the spot of light rests upon the zero mark of the scale. But when the needle moves to one side or the other the spot of light travels over the graduations of the scale, and finally comes to rest at the graduation indicating the difference of potentials sought.

NOTE.—The dyne has been here considered for convenience of illustration as the unit of weight and equal to $\frac{1}{981}$ gramme. This is not strictly accurate, as the dyne is the unit of force—*i.e.*, that force which, acting for one second on a mass of one gramme, gives it a velocity of one centimetre per second. Now, gravity (g) gives a mass of one gramme in one second a velocity of 981 centimetres per second. The weight of one gramme (*i.e.*, the force with which it is attracted to the earth) is, therefore, equivalent to 981 dynes. The value of g varies as the latitude of the place, but for these latitudes its value is very nearly 981.

CHAPTER IV.

VOLTAIC BATTERIES.

THE most simple form of voltaic battery (sometimes called a galvanic, and sometimes a hydro-electric, battery) is made by immersing two dissimilar metals in a jar of acidulated water, and joining them outside the liquid by a wire. The current of electricity produced is stronger when certain substances are used than others, and its direction in the wire is towards the more oxidizable one from the less. That one from which the current flows is called the positive pole of the battery; the other the negative. The following list comprehends the substances most suitable for the purpose, and they are here so arranged that the current flows through the wire from the one nearer the head of the list when any two of them are used, and is strong in proportion to their distance apart in the scale: Carbon, platinum, gold, silver, copper, iron, tin, lead, zinc.

A very convenient form of voltaic couple is made by using plates of zinc and copper in acidulated water (Fig. 29). On first closing the circuit between them by a wire a powerful current begins to pass; but almost immediately its strength commences to fall off, and little bubbles of hydrogen gas appear upon the surface of the copper plate. The weakening of the current is, in fact, due to these hydrogen bubbles, whose effect soon becomes so great as to render the battery to-

Fig. 29.

tally unfit for practical purposes, and to make necessary the adoption of means for their removal. In order to comprehend the means employed it will be necessary to understand the cause of their appearance, and the way in which they act.

Polarization.—By polarization is meant the deposition of these hydrogen bubbles upon the negative plate of a battery. When a piece of pure zinc is placed in acidulated water no appreciable chemical action takes place, even when a piece of copper is also immersed, until metallic connection is made from the zinc to the copper. As soon as this is done, however, the zinc begins to dissolve and hydrogen bubbles to be evolved. The zinc combines with the sulphuric acid in the solution, forming sulphate of zinc, and liberating hydrogen:

$$Zn + H_2\,SO_4 = Zn\,SO_4 + 2H.$$

It will be noticed, however, that all of the hydrogen goes to the copper plate, being apparently carried or translated there through the liquid by the force of the electric current. Now, the weakening effect of the bubbles is twofold: first, as hydrogen is a bad conductor of electricity, they offer a great resistance to the passage of the current through the liquid; second, as hydrogen and copper form almost as strong a galvanic couple as zinc and copper, they set up a current of their own opposed to that of the zinc and copper. To get rid of these ruinous bubbles, and so obtain a battery of constant current, useful for practical purposes, numberless devices have been adopted by different inventors. These may all be classed under the three heads of mechanical means, chemical means, and electro-chemical means.

Mechanical Means.—Smee's battery. The hydrogen may be simply brushed away from the copper plate, air may be forced through the solution in such a way as to carry off with it the hydrogen bubbles, the liquid may

be agitated, or a simpler expedient still, that of Smee, may be adopted.

This consists in covering the surface of the plate with a number of very fine points, from which hydrogen freely escapes. In carrying out this plan Smee replaced the copper plate with one of silver, and covered it with a rough surface of very finely divided platinum (Fig. 30). Smee's battery, however, does not cause the escape of the hydrogen with sufficient rapidity to maintain a powerful current for more than a very few minutes.

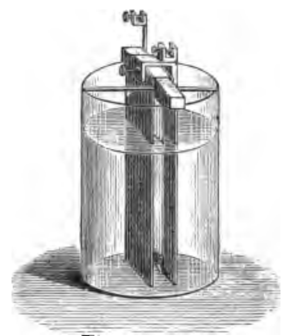


Fig. 30.

Chemical Means.—These consist in adding to the liquid a highly oxidizing substance, such as bichromate of potash, bleaching-powder, or nitric acid, in order to oxidize the hydrogen as soon as it is formed.

Electro-Chemical Means.—These consist in utilizing the power possessed by the electric current of depositing metals from solutions of their salts, in such a way that a solid metal shall be deposited instead of hydrogen. To accomplish this it is necessary to employ double cells, containing two fluids, whose action will be explained farther on.

Single-Fluid Batteries.—The principal single-fluid batteries are Smee's battery (already described), the bichromate battery, and the Leclanché.

The Bichromate Battery (Fig. 31).—This battery is one in which polarization is prevented by purely chemical means. To prepare the solution add five fluid ounces of sulphuric acid to three pints of water, and when this becomes cold add six ounces of finely-pulverized bichromate of potash. As this liquid will attack copper, carbon is used instead; and as it acts on zinc also, even when

the circuit is not closed, the zinc plate is provided at the top with a rod by which it can be raised out of the solution when the battery is not in use. The bichromate battery (of which there are many forms) is very convenient for laboratory use and for other purposes for which a strong current is needed for a short time; but it does not effectually check polarization for more than a few minutes.

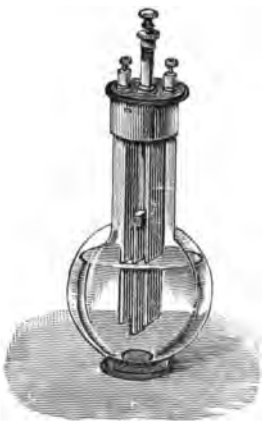


Fig. 31.

Leclanché's Battery (Fig. 32).—In this battery also prevention of polarization is attempted by purely chemical means. Zinc and carbon are used, as in the bichromate battery, but a solution of sal-ammoniac replaces the exciting liquid there used, and powdered binoxide of manganese—a substance which slowly yields up oxygen and thus destroys the hydrogen bubbles—takes the place of the bichromate of potash. In the later forms of Leclanché's battery a plate of carbon is inserted between, and in connection with, two compressed prisms made each of peroxide of manganese and carbon, the three being held together by strong rubber bands. They are secured to the cover which fits over the jar, as is also a rod of amalgamated zinc. The Leclanché battery is admirably suited for telephone lines, house and hotel annunciators, burglar-alarms, etc., where continuous work is not required. It is simple and cheap, and, after being once put in operation, requires no farther attention what-

Fig. 32.

ever. It does not furnish as strong a current as the bichromate battery, but it gives very much less trouble.

Two-Fluid Batteries.—It is in two-fluid batteries only that perfectly constant currents are obtained and polarization thoroughly prevented. Three of the most widely used two-fluid batteries are the Daniell, the Bunsen, and the Grove, and there are many modifications of each of these.

Daniell's Battery (Fig. 33).—In the Daniell element the zinc stands in the acid solution, while a sheet of copper stands in a solution of sulphate of copper, the two liquids being separated from each other by a porous diaphragm. The battery is made in many forms. In some the zinc stands in an inner porous cell, while the copper stands in its solution in the outer cell or jar; in others the zinc is bent into the form of a hollow cylinder and stands in the outer glass jar, surrounding the porous cup containing the copper and sulphate. In all, however, the action is the same. When the circuit is closed the acid attacks the zinc, forming sulphate of zinc and liberating hydrogen. The hydrogen then starts towards the copper plate, but, meeting the sulphate of copper, it displaces therefrom the copper, forming sulphuric acid, while the copper is deposited upon the copper plate.

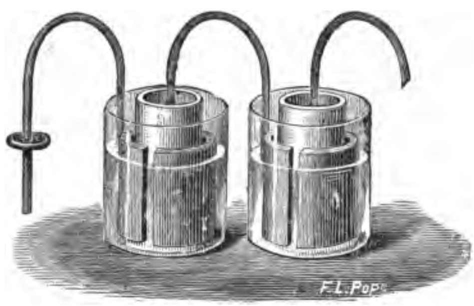


Fig. 33.

$$Zn + H_2\,SO_4 = Zn\,SO_4 + 2H, \text{ and}$$
$$2H + Cu\,SO_4 = H_2\,SO_4 + Cu.$$

The Gravity Battery (Fig. 34).—It is found in practice that the porous cup becomes in time impregnated with copper, especially if much used upon an open or broken circuit; the porous cup is, moreover, somewhat expensive. The gravity battery was therefore devised, which has no porous cup, and in which the necessary separation of the liquids is maintained by taking advantage of their different densities. The zinc is suspended in a dilute solution of sulphate of zinc, and the copper lies at the bottom of the jar in a saturated solution of sulphate of copper. The gravity battery is better adapted than any other for continuous work on telegraph lines, as it furnishes a very constant current and is not liable to get out of order.

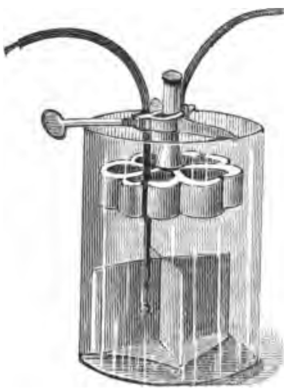


Fig. 34.

Grove's Battery (Fig. 35).—In the Grove element zinc and platinum are the metals used. The former is usually bent into a cylindrical form and placed in a glass jar containing a weak solution of sulphuric acid, while the latter stands in a porous jar holding strong nitric acid and surrounded by the zinc. When the circuit is closed the zinc dissolves in the acid, and the hydrogen evolved passes into the porous jar and combines with the nitric acid to form water and nitrogen

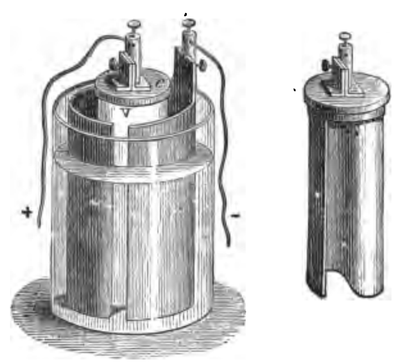


Fig. 35.

peroxide gas. This gas, being very soluble in nitric acid, does not form upon the platinum plate and produce polarization, but it tends rather, by dissolving in the nitric acid, to lessen the already slight resistance which that liquid offers to the passage of the current through the battery from the zinc to the platinum. The battery gives a strong

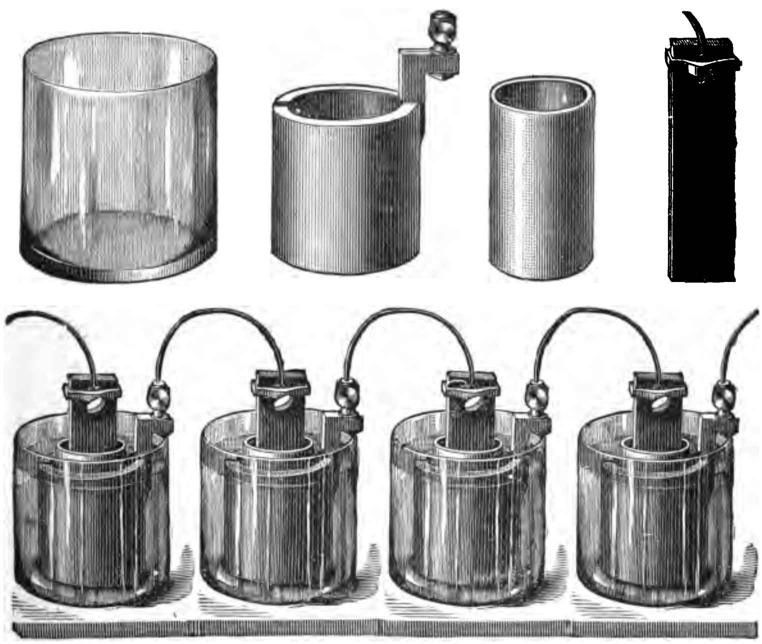


Fig. 36.

and constant current, and it was largely used at one time in this country for working telegraph lines. The fumes of nitric peroxide, however, which rise from it, are extremely disagreeable and irritating to the lungs, and impair greatly the value of the battery for practical use.

Bunsen's Battery (Fig. 36).—In this battery, sometimes called the carbon battery, the expensive pole of platinum is replaced by one of carbon. As will be seen

by referring to the list already given, this combination gives a greater current than that of zinc and platinum. The Bunsen cell is, however, somewhat more difficult to keep in order, and great care must be used in making the connection of the wire to the hard carbon. In some forms the zinc is made in the form of a hollow cylinder embracing the porous jar which contains the carbon. In this case the carbon is provided at the top with a heavy copper ring which supports a binding-screw. Opposite to this binding-screw the curve of the carbon is transformed into a plane surface, so that a wire placed in between the flat surface of the carbon will, when the binding-screw is screwed down upon it, make a good connection. The wire is usually flattened at the point of connection, and is covered with platinum on the side next the carbon. A solution (electropoion) of bichromate of potash and sulphuric acid is often used instead of the nitric acid.

CHAPTER V.

LAWS OF CURRENTS.

Electro-Motive Force.—We have seen that electricity tends to fall from a highly electrified place, or one possessing a high potential, to one of less potential, so that a difference of potential between two points exerts a certain force upon a quantity of electricity, which force tends to move it. To this force is given the name electromotive force. As the difference of potential between two points may vary, the electro-motive force produced thereby may vary; and as a great difference of potential occasions a rapid and vigorous passage of current, while a slight one occasions a slower and weaker one, we may say that the strength of current in any conductor is proportional to the electro-motive force.

Strength of Current.—If we hold a wire, through which a current from one cell of a battery is passing, over and parallel to a magnetic needle, the needle will be deflected (Fig. 37). If now we increase the number of cells we shall find that the amount of deflection is also increased. As the current exerts in some way a deflecting force upon the needle, we have evidently increased its strength by increasing the number of batteries. Suppose that the batteries used were Dan-

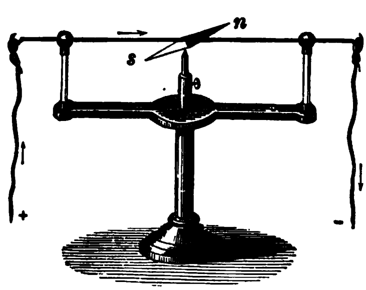


Fig. 37.

iell's (any other would do as well), and that we connected the cells in what is called "series"—that is, we connected the zinc of one cell to the copper of the next, and so on (Fig. 38). Now, the difference of potential between the

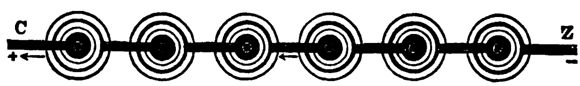


Fig. 38.

first zinc and the last copper will be equal to the sum of the difference of potentials between all the zincs and coppers. The electro-motive force set up is, therefore, greater than with one cell, and this accounts for the greater strength of the current.

Resistance.—But we can get increased strength in another way. Suppose, instead of using more cells, we kept the one cell and used a wire twice as thick. We should find that we obtained a greater deflection of the needle. If now we use a smaller wire we shall find that we get a smaller deflection. We shall find also that we can obtain the same results by using wires made of metals which are better or worse conductors than our first wire. If, for instance, we first used an iron wire and then used a copper wire, we should get a greater deflection in the latter case than in the former. We thus see that the strength of a current depends upon the conductivity of the medium through which it flows. It is customary in electrical science, however, to consider not so much the conductivity of a wire as the converse of its conductivity, or its *resistance.*

Ohm's Law.—Dr. Ohm discovered the important law that "the strength of the current varies directly as the electro-motive force, and inversely as the resistance of the entire circuit." This law may be said to form the foundation of nearly all the computations made in electrical science.

Unit Strength of Current.—The effect which a current produces upon a needle obviously varies with the strength of the current and the distance at which it acts upon the needle. As a current consists of a certain number of units of electricity moving from one point to another, its force upon a needle varies inversely as the square of the distance over which it acts. In order to get an expression for unit strength, it is clear, then, that we must assume that the distance between the conductor and the pole of the magnet-needle is unit distance—*i.e.*, one centimetre. As the effect upon the magnet-pole obviously varies with the strength of that magnet-pole, we must also assume a magnet-pole of unit strength. The unit of force we have already determined upon—the dyne. Now, the strength of a current depends upon the number of units of electricity that pass a given point in one second, so that we have unit strength when one unit passes in one second. Again, the number of units of electricity acting upon the magnet-pole must be greater in a long length of wire than in a short one, so that we must assume that the conductor is of unit length also. A consideration of the above conditions, then—*i.e.*, that the conductor must be one centimetre long, one centimetre distant from a unit magnet-pole, and act on it with a force of one dyne—leads us directly to the conclusion that— 6

A current of unit strength is one such that if a conductor one centimetre long carrying it be bent into an arc of one centimetre radius, it will act with a force of one dyne on a unit magnet-pole placed at the centre.

The unit quantity of current electricity is, therefore, the quantity of electricity carried in one second by a current of unit strength. 7

The unit of current electricity thus obtained is called the "electro-magnetic" unit to distinguish it from the unit we have hitherto considered, called the "electro-

static" unit. The electro-magnetic unit of electricity is very much larger than the electro-static unit.

Electro-magnetic Unit of Potential.—This is
8 determined by the consideration that it shall require the expenditure of one erg of work to raise an electro-magnetic unit of quantity through one unit of potential. As the electro-magnetic unit of electricity (called the electro-magnetic unit of quantity) is very much larger than the electro-static unit, the electro-magnetic unit of potential must be correspondingly smaller than the electro-static. An electro-magnetic unit of electricity, therefore, in falling through one electro-magnetic unit of potential, must perform just one erg of work.

As by Ohm's law the strength of current is proportional to the electro-motive force and inversely proportional to the resistance, then if we express strength of current, electro-motive force (or difference of potential), and resistance in units, the strength of current must be equal to the number of units of electro-motive force divided by the number of units of resistance. Indicating the first by C, the second by E, and the third by R,

$$C = \frac{E}{R}$$

9 **Unit of Resistance.**—Solving the above equation with reference to R,

$$R = \frac{E}{C}$$

So we see that a conductor has unit resistance when the current through it is equal numerically to the difference of electro-motive between its ends; or when a difference of unit potential between its ends will produce a current of unit strength.

Laws of Resistance.—1. The resistance of a conductor is proportional to its length. A wire two miles

long will have twice as much resistance as a similar wire one mile long.

2. The resistance of a conductor is inversely proportional to its area of cross-section. Wire one-half inch thick will, therefore, have four times as much resistance as wire one inch thick.

3. The resistance of a wire of given length and thickness depends upon the specific resistance of the material of which it is made.

Capacity.—It is clear that if we electrify a body by 10
imparting to it two units of electricity we raise its potential twice as high as if we impart to it only one unit, because it would require twice as much work to bring up to it a positive unit of electricity. A little consideration will also show us that if we impart two units of electricity to a large body we will not raise the potential of its surface so high as we would the potential of the surface of a small body to which we also imparted two units. In the case of two spheres, for instance, one having a radius of two centimetres, the other a radius of one centimetre, the repelling force of each would act as if concentrated at the centre; but as the surface of the former is twice as far from its centre as the surface of the latter is from its centre, and as the force of repulsion varies inversely as the square of the distance, the repulsive force at the surface of the small sphere would be four times that at the surface of the large one. Consequently, it would require more work to bring a plus unit up to its surface than to that of the large sphere. The large sphere, then, has the ability to receive more electricity before its potential rises to a certain point than the small one has. This ability of a body to hold electricity is called its "capacity." Its importance is obvious, when we recollect that if we connect a Leyden jar or other body to a source of electricity, the receiving body will receive electricity until its potential is equal to that of the source, in the same

way that a vessel or reservoir will receive water until the level to which the water rises in it is equal to that of the source. And as a reservoir of large capacity will receive a large amount of water before its level rises to that of the source, so will a conductor of large capacity receive a large amount of electricity before its potential rises to that of the source. Now, it will be remembered that we found that two plates of tinfoil could receive more electricity from a certain source when separated by a thin sheet of glass or other "dielectric" than when not so separated. In other words, we found that the effect of the dielectric was to increase the *capacity*.

Unit Capacity.—A conductor possesses unit capacity when a charge of one unit of electricity raises its potential to one. A sphere of one centimetre radius, if charged with one electro-static unit of quantity, will be raised one electro-static unit of potential; it therefore possesses unit capacity in electro-static measure. But as the electro-magnetic unit of quantity is very large, and the electro-magnetic unit of potential very small, a body, to possess electro-magnetic unit capacity, would have to be enormous. For this reason, as will be shown farther on, the unit of capacity practically employed is one thousand millionth of this unit. It is called a *farad*.

PRACTICAL UNITS.

The "electro-magnetic" units of potential, resistance, and capacity are not suitable for making practical measurements, the units of potential and resistance being much too small, and the unit of capacity much too large. For this reason more convenient units, called "practical units," are employed.

Practical Unit of Potential.—The practical unit of potential, or electro-motive force, is called the *volt*, in honor of Volta. It is equal to 100,000,000, or 10^8, absolute (or C. G. S.) units of potential. C. G. S., it may be

here explained, means centimetre, gramme, second, which are the units adopted for absolute measurements.

Practical Unit of Resistance.—The practical ohm

12 unit of resistance is called the *ohm*, in honor of Dr. Ohm. The ohm is equal to 1,000,000,000 (10^9) absolute, electro magnetic, or C. G. S., units of resistance. $R = 10^9$ … $R = \frac{E}{C}$

13 **Practical Unit Strength of Current.**—This is called the *ampère*. As $C = \frac{E}{R}$, the ampère is clearly equal to $\frac{1}{10}$, or 10^{-1}, of the absolute electro magnetic (or C. G. S.) unit of strength. A current of unit strength carries in one second a unit quantity of electricity. Therefore a current of practical unit strength carries in one second a practical unit of quantity. ampere $C = 10^{-1} = \frac{1}{10}$

14 **Practical Unit Quantity of Current.**—This is called the *coulomb*. A consideration of the preceding paragraph will show that a coulomb is $\frac{1}{10}$, or 10^{-1}, of the C. G. S., or absolute, electro magnetic, unit of quantity. Coulomb

15. **Practical Unit of Capacity.**—This is called the *farad*, in honor of Faraday. As a conductor has unit capacity when a unit charge will raise it to unit potential, the unit of capacity must be equal to the unit of quantity divided by the unit of potential, or $\frac{10^{-1}}{10^8} = 10^{-9}$. The farad, then, is equal to $\frac{1}{10^9}$ C. G. S., or absolute, electro magnetic, units of capacity. Even this unit is too large, however, and the micro-farad, which is one-millionth of the farad, or 10^{-6} farads, is employed instead. In practice one-third-micro-farads are usually employed (Fig. 39). These are condensers containing sheets of tinfoil separated by paraffine-paper. (To express a quantity multiplied by one million the prefix "meg" is used; "meg-ohm," therefore, means one million ohms. To ex-

Fig. 39.

press quantities divided by one million the prefix "micro" is employed; micro-volt means, therefore, one-millionth of a volt. To express the thousandth part of a quantity the prefix "milli" is used; "milli-ampère" means, therefore, one-thousandth of an ampère.)

Simple Circuits.—A simple circuit is represented in Fig. 40, in which C Z represents the battery, and the curved line indicates the conducting wire, whose resistance is R. Now, no battery is composed of such good conducting materials that it presents no resistance to the passage of the current through it, so that in entering into computations regarding them it is always essential to take this resistance into account. Supposing that the sum of the united electro-motive forces of the cells of the battery represented in the diagram to be E, the resistance of all the cells to be B, and that of the wire to be R, then

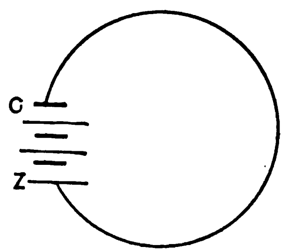


Fig. 40.

$$C = \frac{E}{B+R}.$$

Grouping of Cells.—Suppose we wish to send a message over a wire 200 miles long, of which each mile has a resistance of 13 ohms, making the total resistance 2,600 ohms, and that we know the instrument at the other end of the line requires a strength of current of .01 ampères (or 10 milli-ampères) to work satisfactorily. C then must be as great as .01. Suppose we have 50 Daniell cells, the electro-motive force of each cell being 1 and the resistance 2. Then, over the line, the current from one cell would be

$$\frac{E}{B+R} = \frac{1}{2600+2} = \frac{1}{2602},$$

a current too small for our purpose.

Suppose we now put the 50 cells in series; then the electro-motive force of the battery will be 50, and the resistance 100. The current furnished by all the cells on the line will then be

$$\frac{50}{100+2600}=\frac{50}{2700}=.018+\text{ milli-ampères.}$$

If we place the cells, not in series, but in parallel or multiple arc—that is, if we connect the copper plates of the different cells together and the zinc plates together

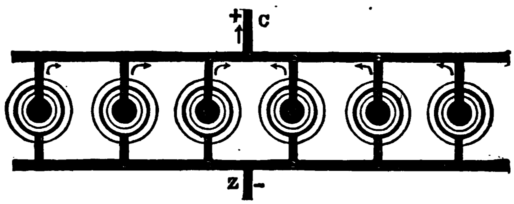


Fig. 41.

(Fig. 41)—then the electro-motive force of the whole battery will be only that of one cell. The resistance of the fifty cells will, however, be only one-fiftieth of that of one cell, because the resistance of a conductor varies inversely as its section, and by combining the cells in the manner described we have multiplied the section of the plates by fifty. The current, then, through the wire will be

$$\frac{1}{\frac{2}{50}+2600}=\frac{1}{2600.4}.$$

So we see that for this case, with a wire of so much resistance, we can get better results with the cells in series than in parallel.

But if we have an extremely small external resistance, say one-tenth of an ohm, then, if we arrange the cells in series, the current from fifty cells will be

$$\frac{50}{100+.1}=\frac{50}{100.1},$$

while if we put the cells in parallel we will get a current of

$$\frac{1}{\frac{2}{50}+.1}=\frac{100}{14}.$$

In this case, therefore, we find that we can get a stronger current by putting the cells in parallel.

A general expression for the current furnished through any resistance by any number of cells arranged in any form can be easily arrived at. Suppose that we have a branches of cells, in each of which branches are b cells; the outside resistance being R, the electro-motive force of each cell E, and the resistance of each cell B, then the current will be

$$C=\frac{bE}{\frac{b}{a}B+R}.$$

As a rule for grouping cells, the strongest current, it can be proved, will be attained with any number of cells when $\frac{b}{a}B=R$; that is, when the resistance of the battery is equal to the outside resistance.

Thus we see that when the external resistance is great the internal must be great, and that when it is small the internal resistance must be small also. A little reflection will show us that the same is true of instruments to be worked on lines of great or small resistance. If, for instance, the line is long and of great resistance, the current over it will be small; while if the line is short and of low resistance the current will be greater. In the former case we shall have to wrap a great many turns of wire around the soft iron in order to magnetize it to sufficient strength. In the case of a line of low resistance, however, the electro-motive force operating the current will be low; so that if we should wind a great many coils around the soft iron we should add so great a resistance

as to materially impair the strength of the current. On long lines, therefore, it is the usual practice to employ instruments wrapped with many turns of fine wire, and on short lines to employ instruments having fewer turns of coarser wire.

Branch or Shunt Circuits.—Suppose a current to divide, on reaching the point T, into three branches (Fig. 42) whose resistances are a, b, and c respectively. Then, if e denotes the difference in potential between T and T′, the current in a will be $\frac{e}{a}$, in b will be $\frac{e}{b}$, and in c will be $\frac{e}{c}$.

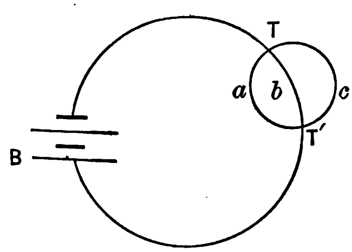


Fig. 42.

The strength, then, in each branch will be inversely proportional to its resistance. Now, as the sum of the currents in the branches must be equal to the whole current,

$$C = \frac{e}{a} + \frac{e}{b} + \frac{e}{c} = \frac{e}{R},$$

where R is the combined resistance of a, b, and c. Therefore

$$\frac{1}{a} + \frac{1}{b} + \frac{1}{c} = \frac{1}{R}$$

$$R = \frac{abc}{ab + ac + \cancel{ab}}.$$ bc

If there are two branches, the same course of reasoning shows us—

$$R = \frac{ab}{a + b}.$$

Development of Heat by Currents.—The resistance which a wire offers to the passage of electricity necessitates the expenditure of a certain amount of energy

in order to overcome it. The energy so expended will appear in the form of heat in the wire, so that its temperature will rise. If, therefore, we place a coil of wire traversed by a current in a vessel containing any suitable liquid, such as water or alcohol, into which dips a thermometer, the temperature of the water will be raised to an extent which will be shown by the thermometer (Fig. 43). By conducting a careful series of experiments, and comparing the heating effects produced when wires of different resistances and currents of different strengths were used, Joule was able to arrive at an expression indicating the relations between the heating effect, the current, the resistance, and the time. He found that—

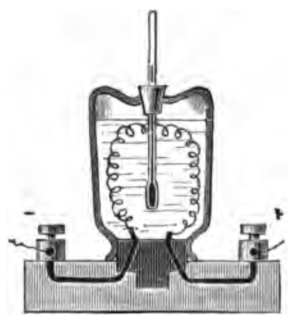


Fig. 43.

1. The number of units of heat developed by a current in a conductor is proportional to the resistance of the conductor. (A heat-unit is the amount of heat necessary to raise 1 gramme of water 1° C.)

2. The number of units of heat developed is proportional to the square of the current and to the time during which the current flows.

These laws can be theoretically deduced as follows:

We have already seen that the work done by a unit of electricity in falling through a unit difference of potential is one erg. Letting Q equal the number of units that pass in a certain time, and E the difference of potential,

$$W = QE;$$

as Q equals the whole number of units of electricity that have passed during the time,

$$Q = Ct,$$

where C is the strength of current reckoned in ampères—

that is, the number of units of current that pass in one second—and t is the number of seconds. Therefore,

$$W = CtE.$$

But Joule discovered also that heat and work can be expressed in terms of each other, and that one heat-unit—that is, the amount of heat necessary to raise one gramme of water through 1° C.—is equal to 42×10^6 ergs of work. Therefore, letting H = the number of heat-units,

$$\frac{W}{42 \times 10^6} = H.$$

$$H = \frac{CtE}{42 \times 10^6}.$$

Now, as $C = \frac{E}{R}$, $E = RC$, and $CtE = C^2Rt$; therefore,

$$H = \frac{C^2Rt}{42 \times 10^6}.$$

C and R are here expressed in C. G. S. units. We have already seen that the unit of C used in practice is 10^{-1} of the C. G. S. unit, and that the unit of R used in practice is equal to 10^9 C. G. S. units. Reducing now to the practical units,

$$H = \frac{C^2Rt}{42 \times 10^6} \times 10^{-2} \times 10^9 = \frac{C^2Rt}{4.2} = C^2Rt \times .24.$$

This formula gives the total number of heat-units developed in any wire of resistance R, but it does not indicate the *temperature* to which it will be raised. This is dependent upon other conditions in addition. If the resistance is that of a long length of coarse wire, the heat developed may not raise the temperature to a perceptible degree, because it is distributed through so large a solid. If, however, the same amount of resistance be occasioned by a short length of fine wire, the number of heat-units developed will be the same, but, as it will be concentrated in

a small space, it will have much greater effect on the temperature of the wire. For wires of equal length, the resistance varying inversely as the square of the diameter, the heat developed will be concentrated in an amount of metal varying inversely as the square of the diameter, so that the rise of temperature at any one point will vary inversely as the fourth power of the diameter.

Electrolysis.—It will be remembered that we found that the currents of voltaic batteries are subject to an opposing force called polarization, due primarily to decomposition of the liquid, and produced by the electric current. This decomposition, or "electrolysis," as it is called, can be easily observed if we invert two tubes filled with water in a vessel of water, and introduce therein two wires from a battery (Fig. 44). Oxygen and hydrogen will be given off almost immediately, oxygen gathering in the tube over the wire from the positive pole, and hydrogen in the tube over the wire from the negative pole. The former wire is termed the positive electrode, or anode, and the latter the negative electrode, or cathode. On measuring the two gases in the tubes it will be found that there is very nearly twice as much hydrogen (by volume) as oxygen, the proportions in which they are found there being almost exactly those in which they combine. A more striking experiment can be performed by using sulphate of copper, into which dip two pieces of platinum connected with the poles of a battery. On passing a current through the liquid the latter is split up into metallic copper, which is deposited upon

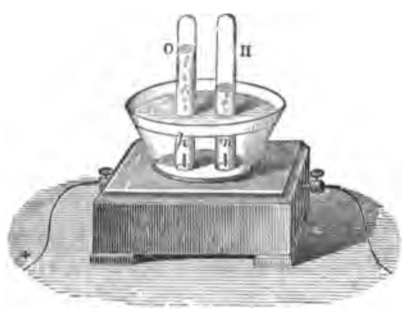


Fig. 44.

the negative electrode, and sulphion (SO_4), which combines with the water, forming sulphuric acid and oxygen.

$$Cu\,SO_4 = Cu + SO_4.$$

$$SO_4 + H_2O = H_2\,SO_4 + O.$$

The oxygen thus liberated goes to the positive electrode (anode) and rises in bubbles.

Ions.—The constituent parts into which a liquid is electrolyzed are called *ions;* that part going to the anode being called an *anion*, the other a *cathion.* Anions are supposed to be electro-negative, because they seem to be attracted towards the positive electrode; while cathions are supposed to be electro-positive, because they seem to be attracted by the negative electrode.

Laws of Electrolysis.—1. The amount of ion liberated at an electrode in a given time is proportional to the strength of the current.

2. The amount of electrolytic action is equal at all points of a circuit.

3. The amount of ion liberated per second is equal to the strength of current multiplied by the amount of that ion deposited in that time by a current of unit strength. This amount is called the "electro-chemical equivalent" of the ion. It has been found by experiment that one coulomb can deposit .0000105 gramme of hydrogen. This number expresses, then, the electro-chemical equivalent of hydrogen, as one coulomb is the quantity of electricity passing in one second when the current is of unit strength.

Electrical Writing.—The power of a current to deposit metals from solutions of their salts gives a convenient way of testing for weak currents. If we dissolve a few crystals of iodide of potassium in water, to which we then add a little starch, we will have a very sensitive electrolyte. If we moisten a strip of paper with the solution, and lay it upon a metallic surface connected with the

negative pole of a battery, while we apply to the other side a wire connected to the positive pole, the current will electrolyze the solution and liberate iodine. This, combining with the starch, will form iodide of starch, and leave a colored stain upon the paper at the positive electrode, even if the current be weak. If now we use the positive electrode as a pencil, and write upon the paper, we shall produce letters or figures as fast as we move the wire along its surface.

Electrotyping.—This is a process involving the principles of electrolysis. In practice the article to be electrotyped is covered with wax, over which is placed a layer of plumbago to give a conducting surface. The whole is then suspended in a bath of sulphate of copper, in which is also suspended a plate of copper, while wires from the negative and positive poles of a battery or other generator are joined to the former and latter respectively (Fig. 45). The electric current now electrolyzes the solu-

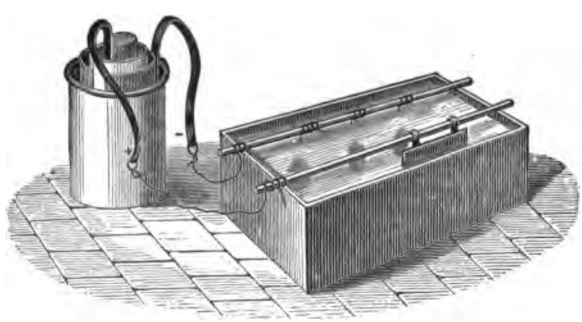


Fig. 45.

tion, and copper is deposited upon the cathode, while the sulphuric acid liberated attacks the copper plate at the anode, which therefore dissolves in the liquid in the same quantity that copper is deposited upon the article to be electrotyped at the cathode.

Electroplating.—This operation is quite similar to that of electrotyping. The article to be gilded or silvered is hung at the cathode in a bath containing double cyanide of gold or silver and potassium, while a plate of the pure metal hangs at the anode. The gold or silver dissolves in the liquid as fast as it is electrically deposited at the cathode, by the electrolyzing action of the current.

CHAPTER VI.

SECONDARY OR STORAGE BATTERIES.

We have seen that to overcome the force of attraction existing between the earth and any body, between a magnet-pole and a dissimilar magnet-pole, or between two dissimilarly electrified bodies, a certain amount of work must be done, and that this amount of work is equal to the work which the attracting bodies will themselves perform if separated and allowed to obey the attracting forces. Now, to separate substances having a chemical attraction for each other requires also a certain amount of work, which amount of work is equal to that which they will themselves perform if allowed to obey the chemical attraction and recombine. If we put a piece of zinc in sulphuric acid, sulphate of zinc is formed, and the two chemicals, in combining, liberate heat. Joule discovered that heat and work can be expressed in terms of each other; and that the heat necessary to raise a cubic centimetre of water one degree Centigrade, or one heat-unit, was equal to $42 \times 1,000,000$ ergs—or, as usually expressed, 42×10^6 ergs—and that, to express the same fact in English units, the amount of heat necessary to raise a pound of water one degree Fahrenheit was equal to 772 foot-pounds. If we know, then, the exact weight of liquid, and then measure by a thermometer the number of degrees through which it is raised by the combination of zinc and sulphuric acid, we get directly the number of heat-units liberated; or, what is the same thing, the number of units of work performed.

If now we send a current of electricity through a solu-

tion of sulphate of zinc or any other solution, and electrolyze it, thereby forcibly severing the attraction between the molecules in combination, we must perform the same amount of work as they themselves performed in combining. Suppose that we send Q coulombs of electricity through a solution, each coulomb disengaging the number of grammes, Z, of an ion, expressed by its chemical equivalent. We then disengage QZ ions in all. Let H equal the number of heat-units given out by a gramme of that ion in entering into the combination from which we have severed it. Then we must do—

$$QZH, \text{ units of heat, or}$$

$$QZH \times (42 \times 10^6) \text{ ergs of work.}$$

But these separated ions tend to reunite with the same energy as we have just expended. In other words, we have stored up this amount of energy. If, therefore, we remove the source of electricity, the energy stored up will expend itself by setting up in the wire an electrical current in the opposite direction to the original one. Devices for thus storing up energy by electrolysis, and liberating it when desired in the form of an electric current, are called *accumulators*, or *secondary*, *polarization*, or *storage batteries*.

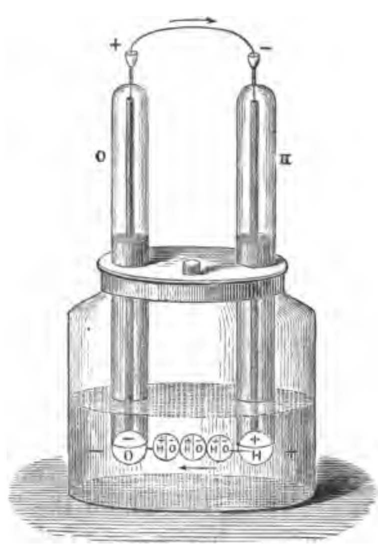


Fig. 46.

Grove's Gas-Battery (Fig. 46).—This is simply the apparatus described in speaking of the electrolysis of water. The name is derived from the fact that

the inverse current set up on removing the source of electricity is due to the action of the two gases collected in the tubes.

Planté's Secondary Battery.—The electro-motive force produced by Grove's gas-battery is very small, however, and it has never been made of any practical use. In 1860 Gaston Planté invented a battery in which the electrolytic fluid is dilute sulphuric acid and the electrodes two sheets of lead (Fig. 47). The oxygen liberated by electrolysis attacks the positive electrode, while a thin film of hydrogen forms over the negative electrode. Only a small amount of oxygen is taken up by the anode, however, and then the generator of the current is removed and the inverse current is allowed to discharge through the wire. The peroxide of lead formed on the anode in a brown film combines with hydrogen and becomes reduced to the monoxide; while at the same time the pure lead of the cathode is attacked by oxygen, so that the surface of this plate becomes also coated with the monoxide. The sulphuric acid, now attacking both plates, covers them with a film of sulphate of lead. When both plates have been reduced to the same condition the current ceases. The battery is then said to be "discharged." It is now connected to the generator, and another current is sent through, but in an opposite direction from the first one. This has the effect of forming a film of peroxide of lead on the surface to which the hydrogen formerly clung, and of sending hydrogen to the plate formerly peroxidized, which reduces this plate to metallic lead. The succession of chargings and dischargings in opposite directions

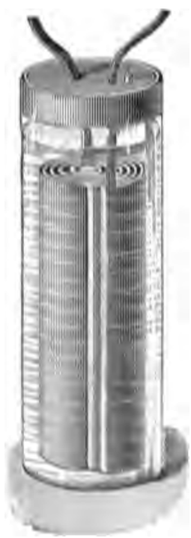


Fig. 47.

causes the plates to be eaten into more and more; and it is kept up until both plates are covered with a thick, spongy layer, affording a large surface for receiving a deposit of peroxide of lead. The process of producing these spongy layers is called "forming," and requires several months in order to get the battery into a satisfactory condition. When this has been accomplished the capacity is very great, because a great deal of peroxide of lead can be deposited upon the spongy plates.

The electrodes of a Planté cell are usually made of two large sheets of lead, which are placed one on top of the other, but separated by narrow strips of gutta-percha, and then rolled up into a spiral form. They are then placed in a cylindrical vessel containing dilute sulphuric acid.

The electro-motive force, as furnished in practice, is usually about two volts. As the resistance of the cell depends upon the size of the plates and their distance apart, it can be made exceedingly small. The Electric Power Storage Co. of England state that the resistance of their cells is only .003 ohm. The current which one cell can give through a small resistance is, therefore, very great. The greater the current furnished, however, the more rapid the expenditure of energy, and the shorter the time during which the discharge can be maintained.

Faure's Battery.—In order to abbreviate the tiresome process of "forming," M. Camille Faure conceived the idea of giving to both plates a preliminary coating of red lead, which is made into a paste and painted upon them. The plates with their coatings are then wrapped in parchment, and a piece of felt is sewed around them. They are now ready for immersion in the dilute acid. The process of forming then pursued is similar to that already described, and results in the same way: that is, one plate is reduced to the metallic state, while the other becomes coated with a thick coating of peroxide of lead. But, as red lead is itself an oxide of lead, and as it is in a

finely-divided condition, the time required in forming is much shorter than when, as in Planté's battery, the two plates are originally hard sheets of metallic lead.

Since Faure's invention became known in 1880 the attention of electricians has been largely turned towards the improvement of storage batteries. Their efforts have been devoted principally towards reducing the weight of the cell—or, to express the idea in different language, towards getting for a given weight a greater amount of surface, and consequently greater capacity—and towards more convenient and economical methods of manufacturing the electrodes. The direction in which they have been working can best be illustrated by giving some of the more important claims in some of the patents taken out in this country. It will be noticed that the claims refer largely to processes of preparing the electrodes.

Camille Faure, January 3, 1882.—"As an improvement in secondary batteries, an electrode consisting of a support coated on one or more faces with an active layer of absorptive substance, so as to be, or instantly become, spongy, and thus capable of receiving and discharging electricity, in contra-distinction to a metallic plate, itself rendered spongy by the disintegrating action of electricity."

J. S. Sellon, June 13, 1882.—"An electrode for secondary batteries having one or more receptacles wherein the active material, or material to become active, is packed, and provided with holes or perforations in the walls of said receptacles. Also, a perforated battery plate, having formed therein recesses or receptacles, and having the active material, or material to become active, packed in said recesses or receptacles."

J. W. Swan, April 4, 1882.—"The method of preparing lead plates for use in secondary batteries, consisting in subjecting the same to the combined action of acetic acid and atmospheric air, and subsequently reducing the carbonate of lead formed to metallic lead."

C. F. Brush, July 4, 1882.—"The method of forming the plates of a secondary battery, consisting in forming receptacles for oxide of lead in its surface, then applying oxide of lead to the plate and within such receptacles, and afterwards subjecting the oxide of lead to pressure."

C. F. Brush, July 18, 1882.—"The herein-described process or method of coating or combining lead or other plates with reduced porous lead, said process consisting in coating the said plates with a suitable compound of lead, and then reducing the latter to the metallic state in the dry way by means of a reducing atmosphere."

Charles F. Brush, August 8, 1882.—"A process for making secondary-battery elements, or material from which said elements can be constructed, said process consisting in covering one or more or all of the surfaces of a suitable metallic and electro-conducting core or body either with superficially oxidized particles of lead, or with a mixture of particles of pure lead and lead oxide, and afterwards applying pressure sufficient to weld said particles or mixture into a compact and coherent mass, and to weld the mass to said core or body."

N. de Kabath, August 22, 1882.—"A compound electrode for secondary batteries formed of very thin sheets of lead having a coating of sulphate of lead placed upon a thicker one and wrapped in artificial parchments."

C. F. Brush, September 5, 1882.—"A secondary-battery element consisting of a perforated plate, sheet, or strip, composed primarily of an alloy of lead and a non-oxidizable substance, with an active or absorptive coating applied thereto."

James A. Maloney and C. H. Koyl, October 17, 1882.—"The combination in a secondary battery of two porous plates having their pores or cells primarily filled, the one with peroxide of lead, or other higher form of lead oxide, the other with a lower form of lead oxide."

C. F. Brush, October 17, 1882.—"A secondary-battery element consisting of a support or body having a coating attached thereto, said coating primarily composed of divided metallic lead and lead oxide, united together into a firm and coherent mass."

C. F. Brush, October 17, 1882.—"A secondary-battery element, or electrode, having a supporting body, or frame, of cast-lead for the active coating or substance, said. body or frame provided with slots, perforations, or openings."

A. K. Eaton, October 17, 1882.—"In a storage battery, the electrodes consisting of lead sponge upon skeleton plates, one electrode being combined with a coating of peroxide of lead in organizing the battery, by which it is made ready for use without the aid of a primary battery."

Eli T. Starr, November 7, 1882.—"A secondary-battery element constructed of a mixture of finely-divided active material with a material which sets or hardens after being brought to a plastic or fluid condition."

Eli T. Starr, November 21, 1882.—"The combination in a secondary battery of a positive electrode constructed of a metal plate or plates, a negative electrode constructed of a porous, active conglomerate or mass, and a porous partition between said electrodes."

J. R. Finney, November 21, 1882.—"A cell having an electrode, or electrodes, of leafy, flaky, or fibrous lead."

E. T. and E. E. Starr, November 28, 1882.—"The combination in a secondary battery of a closed battery vessel, having a valve-opening at its top for the escape of surplus gases generated in charging the battery, the perforated partition forming a space at the bottom of the battery, the electrodes supported by said partition and terminating below the top of the battery vessel to form a space thereat, and tubes or openings

affording a free communication between such spaces at the top and bottom of the battery."

Alfred Haid, February 6, 1882.—"In a secondary battery the alternate plates or frames filled respectively before charging with Prussian blue and oxide of lead; also the combination with the lead-covered or tin-covered iron frames, having apertures for containing the active material, of a suitable covering for retaining such material in place."

James A. Maloney, February 6, 1883.—"In a secondary battery the combination of a plate of black oxide of manganese, a carbon plate, and a liquid containing an ammoniacal salt."

T. A. Edison, March 6, 1883.—"The electrodes for secondary batteries composed of finely-divided metallic lead, having compressed portions for connections."

C. F. Brush, March 13, 1883.—"A secondary-battery element composed of a body, frame, or support constructed of lead, provided with cells, grooves, perforations, or other receptacles, having a coating, or filling, consisting primarily of electrically-deposited coherent lead or other suitable metal, in combination with a battery fluid in which said coating is insoluble."

N. S. Keith, March 13, 1883.—"In a secondary battery the combination of a positive electrode, the active part of which is a finely-divided metal deposited thereon by electro-deposition, and a negative electrode, the active part of which is a spongy, metallic compound deposited thereon by electro-deposition, either one or both electrodes contained in a porous envelope."

T. A. Edison, March 20, 1883.—"An electrode for secondary batteries formed partly or wholly of arborescent metallic lead, and made integral throughout its mass." Electrode is formed by pouring molten lead from a height into water, or into powdered chalk or lime, or by blowing air through molten lead.

C. F. Brush, April 24, 1883.—"A secondary-battery element consisting of a core or body of non-oxidizable material, such as gold, platinum, or equivalent substance, provided with a permanent, active coating."

C. F. Brush, April 24, 1883.—"A method of forming the elements of a secondary battery, consisting in constructing the body or support of the elements with corrugated surfaces, applying or producing on said surfaces an active coating, and afterwards associating said elements together to form the battery."

E. T. and E. E. Starr, April 24, 1883.—"The combination in a secondary battery of electrodes, each consisting of a mass of finely-divided, active material supported and held at its sides between supports which permit access through them of the electrolytic fluid of the battery, and at its edges by a separate support with a porous diaphragm between said electrodes."

In order to charge a secondary battery it is clearly necessary that the charging current must possess a higher electro-motive force than that developed by the secondary battery; for as the current of the latter is in the opposite direction to the charging current, it will overpower it if its electro-motive force is the greater, and will neutralize it if its electro-motive force is equal.

Electro-motive Force and Chemical Force.—An electrolyzing current, in traversing an electrolyte, has not only to overcome the resistance which the liquid offers to the passage of the current, but it also has to overcome the chemical attraction which exists between the molecules it separates, which chemical attraction the molecules seek to obey by setting up in the wire a current in the opposite direction. Let the electro-motive force of this inverse current be e, and suppose that the electrolyzing current during a given time conveys Q units. Now, Q units, in overcoming an electro-motive force of e, must do Qe ergs of work. But Q units,

we have seen, must do an amount of work represented by QZHJ ergs, when passed through an electrolyte, and depositing Z grammes of an ion per unit. Therefore

$$Qe = QZHJ,$$
$$e = ZHJ.$$

In other words, the electro-motive force set up by the effort of an ion to recombine is equal to the product of its electro-chemical equivalent into its heat of combination into Joule's equivalent.

In a battery such as Daniell's, in which both zinc and copper tend to combine with sulphuric acid, the electro-motive force set by the copper is in the opposite direction to that set up by the zinc. The heat of combination of zinc is, however, much higher than that of copper, as zinc has a much greater affinity for oxygen. The electro-motive force of the former triumphs, therefore; but its intensity is reduced by the electro-motive force of the copper. The E. M. F. of zinc, as obtained from the above formula, is about 2.40, while that of copper is about 1.22; so that the resulting E.M.F. is, theoretically, about 1.18.

CHAPTER VII.

THERMO-ELECTRIC BATTERIES.

IF any two of the metals in the following list be joined together, and their junctions heated, they will acquire different potentials, so that, if joined by a wire, a current will circulate therein (Fig. 48). The list is here so arranged that the current will traverse the wire from the metal the nearer the head of the list towards the one nearer the bottom. The latter will, however, have the higher potential, so that the current will flow from it across the junction to the other. The heat applied takes the place evidently of the acid in a hydro-electric battery. The electro-motive force thus produced is called "thermo-electro-motive force":

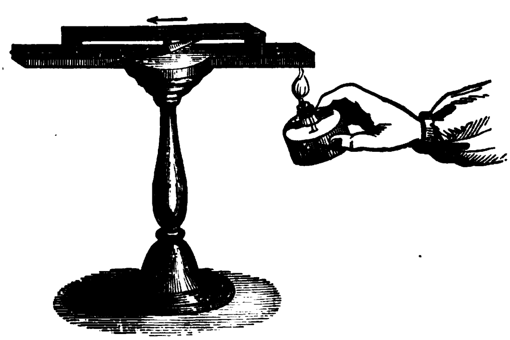


Fig. 48.

Selenium, antimony, red phosphorus, iron, zinc, silver, platinum, copper, lead, nickel, cobalt, bismuth. Selenium is, however, such a poor conductor and so expensive that it is seldom used for this purpose.

The further apart any two metals lie in this list the greater the difference of potential they will assume, and, therefore, the stronger the current they will produce. The greater the heat applied, within certain limits, the

greater also will be the difference of potential. But, in the case of some pairs of metals, a reversal of the current occurs when a certain temperature is reached. With a couple of iron and copper the turning-point is 280° ; so that when heat exceeding this temperature is applied the current traverses the wire from the copper to the iron. The differences of potential assumed by any two of these metals are very much less than those existing between the elements of hydro-electric batteries, and, for this reason, thermo-electric batteries have come but little into practical use; though with "thermo-piles," consisting of a number of thermo couples arranged in series, a considerable electro-motive force may be obtained (Fig. 49). There is much research going on in this field, however, which is believed by many to be the most promising in electrical science. The advantages of getting an electric current directly from heat, without going through the intermediate processes of boiling water to produce steam, using this steam to drive an engine, and using this engine to turn a dynamo-machine, are too obvious to require detailing.

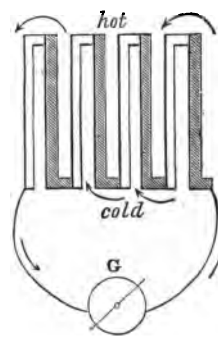


Fig. 49.

The best way of presenting the present state of this art will probably be to give a brief abstract of some of the patents recently taken out, and of some experiments recently made.

M. Brard, of La Rochelle, has made what he calls an "electro-generative slab," or brick, which, when submitted to the action of heat, gives off an electric current. The slab, as made, is a parallelopiped about six inches long, two inches wide, and one inch thick, resembling, therefore, a brick in size and shape (Fig. 49½). The slab, or brick, is enveloped in a sheet of asbestos-paper, from

which two strips of copper or brass protrude. The slab is made of a prism of prepared carbon, separated from nitrate of potash by a sheet of asbestos. The carbon prism is made, it is said, by mixing coal-dust with molasses and tar in such a way as to form a paste, which is then submitted to high pressure in a suitable mould, at the bot-

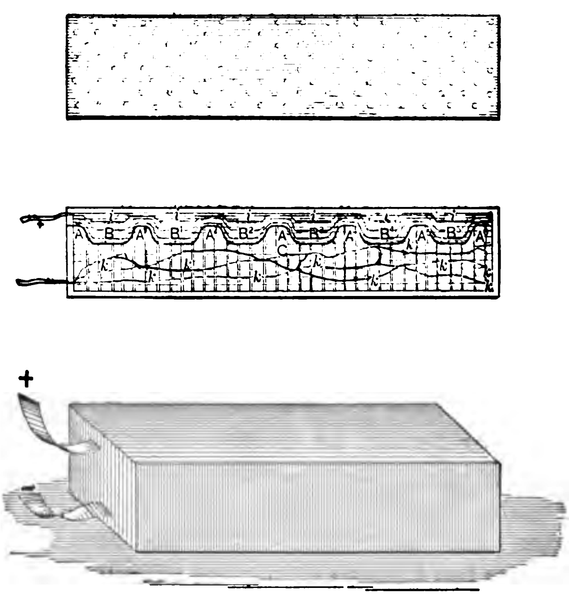


Fig. 49½.

tom of which has been placed a strip of brass or copper, which thus becomes embedded in the mass. One end of this strip projects, and is intended to serve as one of the poles. The mould is so formed that the slab is perforated throughout with numerous small holes, and has imprinted upon it a number of rectangular depressions, which are intended to hold the nitrate. The whole upper surface is then covered with a sheet of asbestos-paper, and over this is put a mixture composed of three parts ashes and

one part nitrate of potash or soda, the ashes being intended to prevent too rapid combustion. The mixture is first melted, and is then poured over the brick very hot and in a sirupy state. A second strip of brass or copper is now embedded in the nitrate before it has had time to cool, and one end of it projects to serve as the positive pole. The brick is now wrapped in the sheet of asbestos-paper, and if it then be put into a hot fire, and the two poles be joined by a conducting wire, a constant current will circulate through the wire from the nitrate pole towards the carbon pole, the combustion lasting, it is said, and therefore the current, for nearly two hours, and of a strength sufficient to ring an ordinary electric bell. As yet, however, accurate data in regard to its performance are wanting.

On August 26, 1877, Paul Jablochkoff patented a thermo-electric battery in which fused nitrates constituted the positive pole and carbonaceous matter the negative, combined with a closed receiver in which the gases generated were gathered. the electric current being, of course, generated by the reaction of the nitrates upon the carbonaccous matter.

On July 12, 1881, Paget Higgs patented a thermo-electric battery which consisted of a coil of wire divided into sections which have alternately a greater and a less degree of mechanical tension.

On July 19, 1881, C. W. Randall patented a thermo-electric battery in which are combined a heating apparatus, which is employed also indirectly to produce a freezing mixture, and one or more thermo-electric elements, which are subjected in certain parts to the heating effect of the heating apparatus, and in other parts to the freezing effect of the freezing apparatus.

On May 24, 1882, Paget Higgs patented a thermo-electro battery in which is the combination of an element having its surface coated with chemically pure iron with one having its surface of nickel, the electro-motive

force being produced by the contact of the iron and the nickel, a number of these couples being arranged about a central source of heat.

On April 24, 1882, Andrew Patterson patented a thermo-electric brick which is a mass of refractory material enveloping one or more thermo-electric couples embedded in it. This furnishes a means for using fusible and oxidizable materials. One claim covers the combination with this refractory brick of an infusible and a fusible substance.

On August 1, 1882, Andrew Patterson patented a battery in which a mass of sulphuret of copper is placed between two blocks of copper, one of which is heated, the other cold. The inventor claims that the thermal current generated by the flow of heat across the junction will be assisted by the current due to chemical decomposition and recomposition which the sulphuret undergoes. On the same date he also patented a battery in which two compact masses of dissimilar thermo-electrically excitable substances are arranged in contact in such manner that heat is applied directly to one, and by conduction across the junction to the other. Both are enclosed in an envelope partially surrounding them.

On March 27, 1883, Samuel J. Wallace patented a battery in which two electrodes, made of conglomerates of coke, ores, etc., lie in chambers or cells which are closed at the bottom by a porous partition. The two cells contain an active electrolytic solution, which stands at a certain height less than that of the electrodes, and below the porous partition are passages communicating with the air and with hot, electro-positive gases formed of hydrogen and sulphurous oxide. The air-passage leads to the negative, the other to the positive, side of the battery. The gases, rising through the liquid and up to the positive electrode, carry with them some of the liquid, so that the liquid comes into contact with both gases and

electrode. A mechanical rotary motion is imparted to the chambers containing the electrodes, which serves to forcibly intermix gases, fluids, and electrode. The electro-positive gases come into contact with the electrolytic fluid and the positive electrode at a temperature above that due to ordinary conditions, and both promote the motion of the electrode and assist the electro-chemical action. An intimate mixture of liquid and gases occurs in the chambers, thereby producing a large extent of triple contact of gas, electrode, and liquid.

On March 13, 1883, Paul Jablochkoff patented a battery, or pile, in which the positive element consists of sodium, potassium, or other metal or substance which oxidizes readily in the air, and the negative element consists of an inert material of porous substance readily permeated by the air. The two metals are separated by a thin layer of porous, non-conducting fabric. The negative element may be a plate of porous carbon, and the exposed surface of the positive element protected by an impervious coating. The battery may be kept inactive, when desired, by immersing it in oil or some other liquid not giving off oxygen, or in a vessel of hydrogen or other gas devoid of oxygen. It can be rendered active again by washing out the oil or other solvent; and its activity may be stimulated by covering it with a damp fabric. After the negative element has become completely oxidized, if an inverse current be passed through it the oxide will be reduced to the metallic state, so that the battery can be used over again. Fig. 50 shows a sodium layer, B, between two sheets of metallic gauze or perforated metal, E. The sodium, becoming oxidized by the action of the atmosphere, forms caustic soda, which takes water from the air; the soda solution permeates the pores of the metal, but a large proportion unites with the nitrogen of the atmosphere, forming nitrate of soda.

Fig. 50.

J. H. Davies patented a peculiar form of thermo-electric battery in England in July, 1882. In this apparatus (Fig. 51) a large vessel, A, contains nitrate of potash, which is melted by heat. In the same vessel is hung a carbon stick, C, and a cage, B, made of fine iron wire of several thicknesses. Into this cage projects a tube, D, which comes from a vessel, E, containing nitric acid, and this vessel has connected to it another tube, F, through which air can be forced. When air is thus forced through F fumes of nitric acid are carried into B, which pass through the interstices of the cage and into the melted nitrate of potash in the vessel A. The inventor states that the carbon and the cage B acquire different potentials, and that, on connecting them outside the vessel by a conducting wire, a current flows through this wire from the carbon to the iron cage.

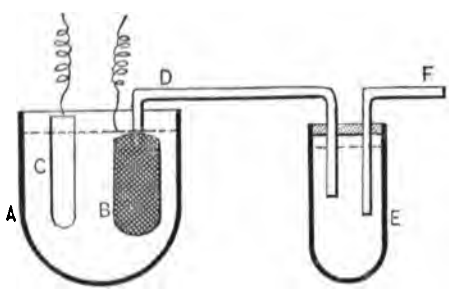


Fig. 51.

From the above it will be seen that very little of praccal value has as yet been accomplished in the line of thermo-electricity, and that inventors and experimenters in this field are groping in the dark, without the guidance of very well defined or understood laws and principles. When we consider, however, that the combustion of zinc in acid is almost the only means used for generating electric currents directly, and that there are so many cheaper substances which, when in connection with another, will also combine with oxygen and produce electric currents, the conclusion is forced upon us that here is a broad field of discovery almost untrodden, and one promising to the successful explorer results boundless in magnitude and importance.

CHAPTER VIII.

ELECTRO-MAGNETISM.

Magnetic Nature of Currents.—We have seen that magnet-poles send out lines of force which act upon magnets and magnetic substances, and we obtained a graphic representation of the action of these lines of force by holding a magnet-pole under a sheet of glass upon

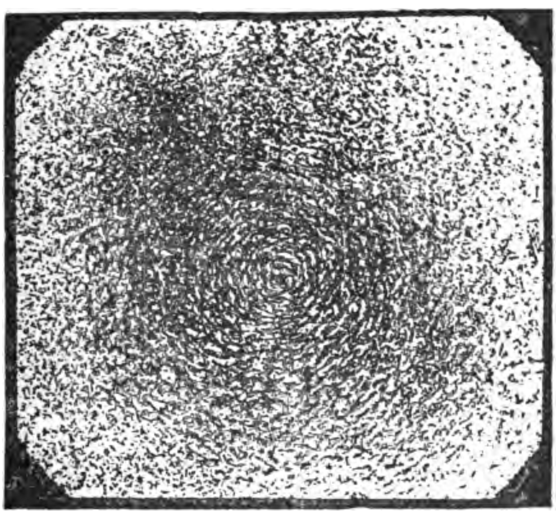


Fig. 52.

which iron-filings had been sifted. We can obtain evidence, by a similar device, that an electric current also possesses magnetic power, by passing a conductor traversed by a current through a small hole bored in a similarly-prepared sheet of glass (Fig. 52). On lightly tapping the glass to overcome the inertia of the filings they will

immediately set themselves in concentric circles, of which the conductor is the centre, thus showing clearly the existence of lines of force of a magnetic character encircling the wire (Fig. 53). A still more satisfactory proof may be obtained if we bend the conductor into the form of a loop (Fig. 54) and bring up a magnet-pole. In the interior of the loop it is clear that all the lines of force run parallel, so that they will all act together and either repel or attract a magnet-pole. If, in the case represented in Fig. 54, we bring up a north pole the pole will be attracted, while if we bring up a south pole it will be repelled. A contrary condition of affairs will be produced if we coil the loop in the opposite direction, as represented in Fig. 55; for a north pole will then be repelled and a south pole attracted. If now we increase the number of coils (Fig. 56) the number of lines of force acting together will be increased, and therefore the attraction or repulsion exerted upon a magnet-pole will be increased. A series

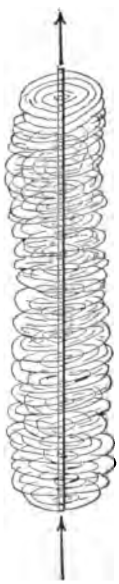


Fig. 53.

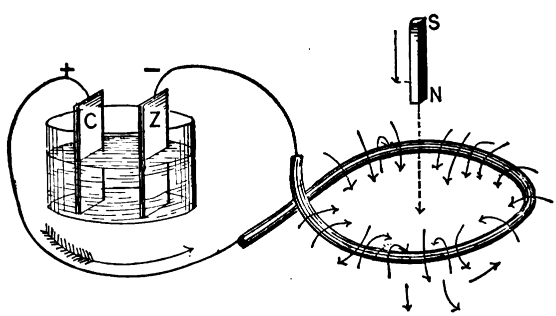


Fig. 54.

of coils, or a "helix," of wire thus arranged is called a "solenoid."

Electro-Magnets.—A still greater magnetic effect

can be produced upon the magnet-pole if we place a bar of soft iron within the solenoid (Fig. 57). Soft iron af-

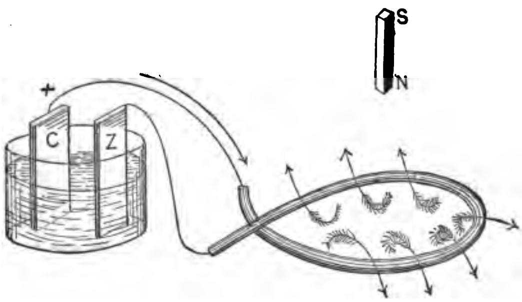


Fig. 55.

fords a better conduction for magnetic lines of force than air does, so that many more of the circling lines of force are brought within the interior of the helix and run through the soft iron. The soft iron is therefore magnetized. It is scarcely necessary to remind the reader that the bare wire

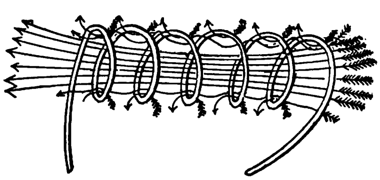


Fig. 56.

should not touch the iron, because iron is a conductor of electricity; and it need not be said that the separate turns should not touch each other, because the current always takes the path of least resistance, and would, therefore,

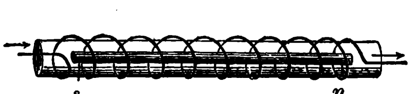


Fig. 57.

simply pass from one turn to another without going around the spiral. If the wire used be covered with an insulating material both difficulties will be obviated. It will be remembered that soft iron has a low coercive force—that is, that it receives and loses magnetism readily. It is for this reason that, as will be seen farther on,

the electro-magnet has such an extended sphere of usefulness. As soon as a current begins to circulate around it the soft iron becomes magnetic, and as soon as the current ceases the magnetization ceases. The magnetism is, therefore, completely under the control of the current.

Positive and Negative Directions of Lines of Force.—The study of the action of all kinds of electro-magnetic apparatus is much facilitated by adopting a uniform and conventional expression for the direction of lines of force. *The positive direction of a line of force is the direction in which a free north pole tends to move;* the negative direction of lines of force is the direction in which a free south pole tends to move. Obviously, then, the positive direction of the lines of force emanating from a north pole is away from that pole; while the positive direction of the lines of force due to a south pole is towards that pole (Fig. 58). Returning now to Fig. 54, we see that the positive direction of the lines of force within the loop must be down, because the free north pole, N, is attracted down; while in Fig. 55 we see that the positive direction of the lines of force must be up, because the free north pole, N, is repelled. Regarding now the direction of these lines as to the length of the conductor, we see that the positive direction of the lines of force encircling a conductor traversed by an electric current is in the direction of the hands of a watch, if we look in the direction in which the current is flowing.

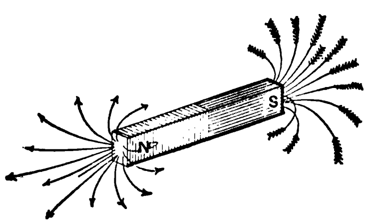


Fig. 58.

Ampère's Theory of Magnetism.—In view of the strong resemblance between permanent magnets and magnets produced by encircling magnetic substances with electric currents, Ampère conceived the theory that the

molecules of magnetic substances are encircled by electric currents; that, as long as no magnetizing force is exerted, the directions of these currents are antagonistic, so that, as a whole, they exert no external effect; that magnetization simply produces a degree of parallelism in the internal currents which is proportional to the strength of the magnetizing current; but that the limit of magnetization is reached when they are made absolutely parallel. In this case the resultant effect of all the little currents is that of one current encircling the outside of the substance. Recurring again to Figs. 54 and 55, we can calculate in what direction these imaginary currents must be. As the positive direction of the lines of force from a north pole is away from the pole, we see that the imaginary electric current around a north pole must be in the direction of the hands of a watch, supposing, as before, *that we are looking along the positive direction of the lines of force.* A similar conclusion will be reached if we consider the action of a south pole, or the action of a loop of wire coiled in the opposite direction. A magnet, then, may be supposed to be encircled by electric currents which flow in the direction of the hands of a clock, to a person looking along the positive direction of the lines of force—that is, from the south towards the north pole (Fig. 59).

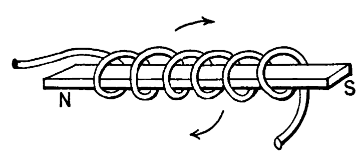


Fig. 59.

Action of Current on Magnetic Needle.—The cause of the deflection of a magnet-needle by placing over and parallel to it a conductor carrying an electric current will now appear very plainly (Fig. 60). If the current be flowing in the direction indicated by the arrow, the positive direction of the lines of force on the under side will be towards the *left of a person swimming in the current and looking down at the needle.* The north pole will con-

sequently be deflected in this direction, and the south pole in the other.

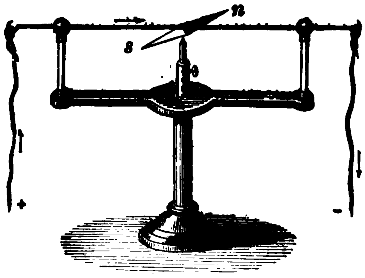


Fig. 60.

Deflection of Conductors by Magnet-Poles. — Suppose, however, the converse case to the above; that is, that the magnet-pole is stationary and the conductor free to move. The force exerted between the magnet-pole, N, and the conductor is clearly the same; therefore *the conductor will be deflected to the left of a person swimming in the conductor and looking along the positive direction of the lines of force.* If the south pole were presented instead of the north, the same rule would indicate the direction of deflection. This deflection would, of course, be in the opposite direction; but the lines of force would run in the opposite direction. The importance of this rule will become apparent when we study the action of electro-motors, in which conductors are rotated by the action of magnets.

Magnetic Actions of Currents on Each Other. — If we pass a current through a wire coiled in the form of a spiral the spiral will shorten itself. If we place two conductors, carrying currents in the same direction, parallel to each other, they will attract each other; but if the currents flow in opposite directions they will repel each other (Fig. 61). The same result will be attained if the conduc-

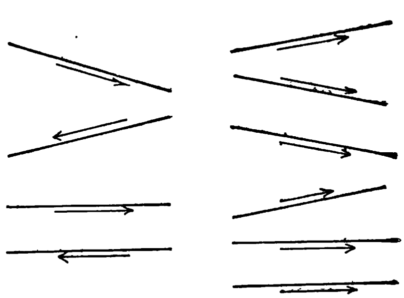


Fig. 61.

tors converge to a common point. The reason for these magnetic attractions and repulsions becomes very plain if we bear in mind the direction of the lines of force encircling the conductors. In the case of two parallel conductors, or conductors converging to a common point, the little lines of force run in the same direction and exert a mutual attraction; while in the case in which the electric currents flow in opposite directions the lines of force run in opposite directions and antagonize each other. A pretty illustration of the effect of attraction can be obtained by passing a current through a suspended spiral whose lower end just dips into a basin of mercury connected to the opposite pole of the battery. The current will cause the attraction of the separate spirals to shorten the length of whole spiral, thus drawing the lower end of the spiral out of the mercury. This will break the circuit, so that the spiral will again lengthen itself, thus immersing its end in the mercury and re-establishing the current. In this manner the spiral will take up a longitudinal vibration and jump up and down into and out of the mercury.

Forms of Electro-Magnets.—So numerous are the uses to which electro-magnets are put that they are made in numberless shapes and sizes. The forms most frequently used are, however, those of the horseshoe magnet, the bar magnet, the one-coil magnet, and the helix or axial magnet. Most of the other forms of electro-magnets are combinations of these.

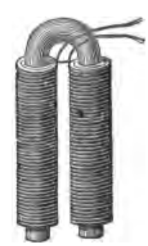


Fig. 62.

The strongest and most popular form is that of the "horseshoe," in which the core is bent around into this shape, or two branches are united by a yoke (Fig. 62). The superiority of this form lies in the fact that both poles are thus brought side by side and in a position to act together.

After a long course of experiments and calculations

upon electro-magnets Count Du Moncel has determined some of the most favorable conditions for the construction and operation of electro-magnets. Some of his conclusions may be briefly stated here.

The most favorable size of wire is that which renders the resistance of the electro-magnet equal to that of the external circuit. This presupposes that dimensions of core, spools, etc., are given.

The thickness of the coils should be equal to that of the core.

The total length of the core, including both arms and the connecting yoke, should be eleven times the diameter of the core.

When, however, the circuit is long and the electric source of feeble energy the magnet should be long and of small diameter. When, on the contrary, the circuit is short and the current strong the core should be of large diameter. Up to the point of saturation the attractive force of an electro-magnet varies irregularly. The customary rule is that it varies as the square of the current; but this is only true for a certain point. Previous to reaching that point the attractive force varies much more rapidly than the square of the current, and subsequently more slowly.

The attraction of magnets for prismatic armatures at a distance is greatest when they are presented flat-wise; but when in contact the attractive force is greatest when they are presented edgewise.

The best condition of electro-magnets, relating to the dimensions of the different parts, is obtained when the two branches connecting yoke and armature are all equal.

The arrangement by which an armature rotates about a pivot near one of the poles is better than that by which it is made to move parallel to the line joining the poles.

The lateral attraction of electro-magnets whose cores

project beyond the helices is less forcible than in the direction of the axes.

Armatures made of permanent magnets aid the attraction only when at a distance and parallel to a line joining the poles. When near, permanent magnets do not experience as strong an attraction as soft iron, for the reason that soft iron can have induced in it a higher magnetization than steel can attain.

If a quick-working electro-magnet is desired the magnet should be short and the armature light.

In the case of tubular electro-magnets the thickness of the tubing should be from one-fourth to one-seventh of the diameter.

Electric Bells.—The electric bell is a combination with a clapper and gong of an electro-magnet and its armature. As ordinarily constructed the armature is mounted in front of the electro-magnet on a piece of spring metal, which holds it at a slight distance therefrom, and which carries at its extremity a clapper arranged in convenient proximity to a gong, in such manner that, when the armature is attracted, the clapper strikes the gong (Fig. 63). When we push an electric button in the room of a hotel or at an elevator landing we merely bring together two springs connected with the circuit of the bell and battery, so that the current is allowed to pass and magnetize the electro-magnet; thus the armature is attracted and the gong struck. But the

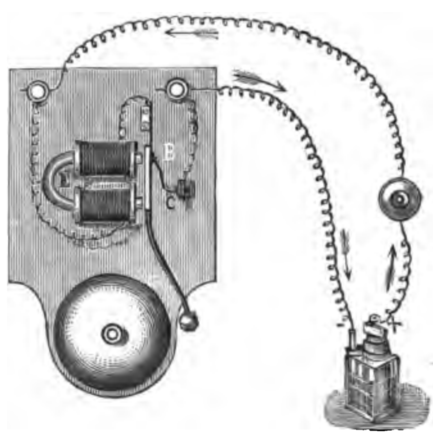


Fig. 63.

movement of the armature separates the two points, B and C, through which the current was flowing; so that the current is thus automatically broken and the armature allowed to spring back. But this motion brings B and C together again, thereby re-establishing the current, so that the armature is again attracted and the gong again struck. As long as we press the button, then, the current is automatically made and broken with great frequency, so that the gong is struck with similar frequency, and therefore gives out a jingling sound. An armature mounted in this way, so as to automatically make and break the circuit, is called a "vibrating armature," and sometimes an "automatic circuit-breaker."

CHAPTER IX.

INDUCTION-CURRENTS.

It will be remembered that we found that a closed circuit bent into a loop will attract or repel a magnet-pole. Faraday discovered the converse of this to be true—viz., that if a magnet-pole be forcibly moved towards or away from a closed circuit it will induce a current of electricity in it (Fig. 64). Faraday observed that the direction of the

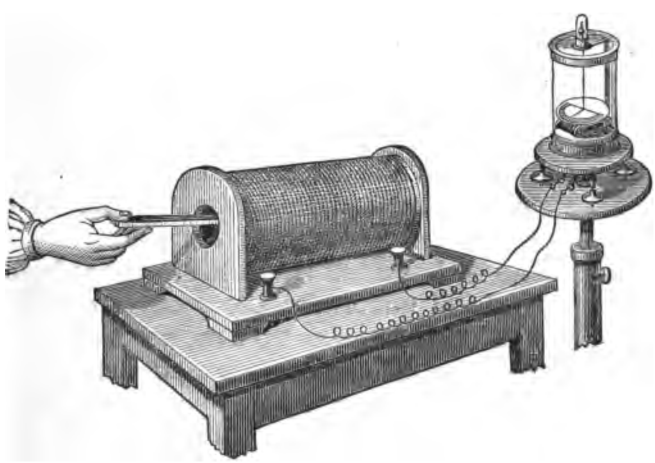


Fig. 64.

current induced was such as to oppose the motion producing it. In other words, if he brought a north pole towards a coil of wire whose ends were connected, the current induced was such as to form a north pole at the end of the coil, while the current induced by the recession of the

north pole was such as to form a south pole. Reverse effects were produced with a south pole, the approach of the south pole creating a south pole at the end of the coil, and the recession of the south pole creating a north pole. In all the cases the current lasted only while the motion lasted, showing that the mechanical energy of the motion was the cause of the electrical energy produced, the magnet-pole acting merely as the medium or vehicle.

The knowledge which we possess that a conductor traversed by electricity is encircled by little lines of force leads us directly to the inference that the direct effect of the motion of a magnet-pole is to set up these encircling lines about the wires of the coils, and that the effect of these is to produce a current. As the direction of the current is such as to create an opposing force to the motion of the magnet-pole, it is clear that a certain amount of work must be done if the motion is persisted in. This mechanical work is then converted into electrical work. Therefore the greater the work the greater the current. As the resistance of the circuit and the weight of the magnet are constant, the *electro-motive force set up in the coils must vary with the rapidity of the motion.*

Direction of Induced Currents.—It has been said that, for the sake of uniformity, the positive direction of lines of force is taken as away from the north pole. Bearing this in mind, we can predict in what direction currents will be set up in any circuit, by the approach or recession of any magnet-pole.

In the case of the magnet-pole and circuit already considered the approach of a north pole induces a north pole at the near end of the circuit. That is, looking along the positive direction of the lines of force from the north pole of the magnet, the induced current will clearly be in the direction the opposite to that in which the hands of a watch move. The recession of this north pole will induce a south pole at the near end of the coil, so that the cur-

rent will be, to a person looking along the positive direction of the lines of force, in the same direction as that in which the hands of a watch move. By the approach of a north pole we evidently increase the number of lines of force embraced by the circuit, and by its recession we decrease them. We may, therefore, make the general rule that—

An increase in the number of lines of force embraced by a circuit induces a current in the opposite direction to that in which the hands of a watch move, while a decrease in the number of lines of force induces a current in the same direction as that in which the hands of a watch move, the line of sight being in both cases along the positive direction of the lines of force.

The latter is called the positive direction of a current, the former the negative.

Suppose we adopt another method of altering the number of lines of force embraced by a circuit by keeping the distance between the circuit and the magnet-pole constant, but increasing the area enclosed by the circuit. This we can do by using the three wires S C, C D, and D T (Fig. 65), upon which we lay the conductor, A B. If we now move A B to the right the number of lines of force embraced by the circuit A B C D will be increased, while if we move it to the left the number will be decreased. In the former case the induced current will be that shown by the arrow; in the latter case that shown by the dotted arrow. From this we are led to the following modification of Ampère's rule:

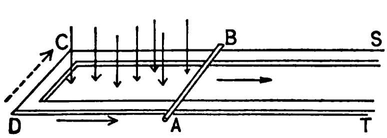


Fig. 65.

Suppose a man swimming in a conductor to look along the positive direction of the lines of force; then if the conductor be moved towards his right hand he will be swimming with the current induced by this motion.

Unit Electro-motive Force of Induced Currents.—We have seen that the electro-motive force of an induced current varies with the rapidity of motion of a given magnet-pole, and we have also seen that the number of lines of force added varies in the same ratio. If a magnet-pole with a strength of two be moved with unit velocity, twice as much work will have to be done as if a pole with a strength of one be moved with the same ve-

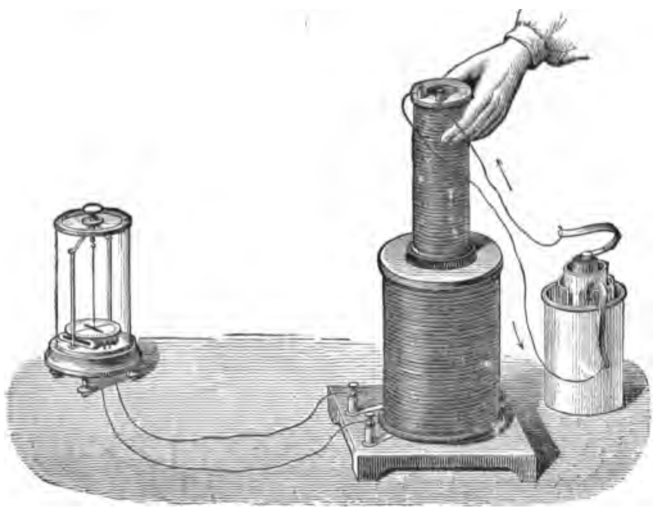


Fig. 66.

locity. To get an expression for unit electro-motive force it is necessary to decrease the number of lines of force at unit rate. In Fig. 65 let the conductor, A B, be made *one centimetre long, and moved to the left at unit rate and in a field of unit intensity; the lines of force will then decrease at unit rate, and a positive current of unit electro-motive force will be induced.* This unit E.M.F. is, of course, in C.G.S. units.

Induction of Currents by Currents.—As the induction of currents is due to the increase and decrease of lines of force, it is clear that we can use solenoids or elec-

tro-magnets through which currents are passing, instead of magnets (Fig. 66).

For the same reason we can induce currents in a coil of wire by opening and closing the circuit in a contiguous coil, or by decreasing or increasing its strength (Fig. 67).

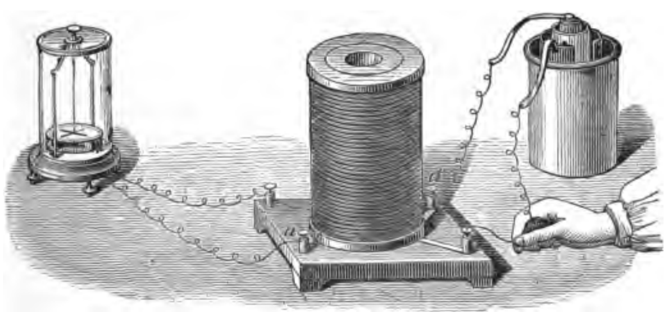


Fig. 67.

The current induced on closing or increasing the inducing current is an inverse current; that induced on breaking or decreasing the inducing current is a direct current, the latter being in the same direction as the inducing current, the former in the opposite direction.

Induction-Coils.—These are devices for producing currents of high electro-motive force in one circuit by rapidly making and breaking the circuit in a contiguous circuit. In induction-coils, as usually constructed, a coil of coarse wire connected with a battery is surrounded by a long coil of fine wire, the wire in each coil being, of course, insulated. When now the current in the coarse or "primary" coil is made and broken, or increased and decreased, induced currents in alternate directions circulate through the fine wire, or "secondary coil."

Extra Currents; Self-Induction.—If two coils belong to the same circuit the inductive effect of each upon the other will be the same as if they belong to different circuits. If, therefore, a current is sent through two par-

allel, or nearly parallel, coils of wire, the inductive effect of each, when the current is made, will be to induce an inverse current in the other. In the case of a large number of coils they will all act upon each other; so that the inductive effect will be greater the greater the number of coils. The effect of the inverse current thus induced in each coil is to check momentarily the rise of the current to its full strength.

If the coils be wrapped about a bar of soft iron, as is the case with an electro-magnet, the inductive action will be increased, because the magnetism created in the bar will increase the number of lines of force in each coil, and therefore increase the inductive power of that coil.

When, on the other hand, the current in the wire is broken the inductive effect of the coils on each other will be to set up a direct current. This effect is also increased by having a large number of coils and winding them around a bar of soft iron. The effect of this extra current is, therefore, to momentarily *increase* the strength of the current just as it is broken. The extra current on breaking is sometimes of such electro-motive force that a spark jumps across the interval, and if a person be holding the ends of the conductor he will experience a sharp shock. These self-induction currents are of the greatest importance in telegraphy and electric machinery. Extra currents are found on opening and closing the circuit in straight wires when they are long, but they are not so intense as when the wires are wound in coils.

Ruhmkorff's Coil.—The most striking exhibition of induction-currents can be obtained from a Ruhmkorff coil. This consists of a primary coil of coarse wire wrapped about an iron core consisting of a bundle of wires, and surrounded by a secondary coil consisting of many turns of very fine wire. The primary coils are coarse, in order that they may carry very strong currents, and thus develop a large number of lines of force; and the core is

made of iron to increase this number. The reason for making the core of wires instead of making it solid is because a solid core is not magnetized and demagnetized as readily as one made of small pieces. In the circuit of the primary coil is an "interrupter," or automatic circuit-breaker, somewhat similar to that shown in Fig. 63, by which the circuit is rapidly made and broken. With delicately-constructed apparatus this can be accomplished many hundred times per second. Each time that the cir-

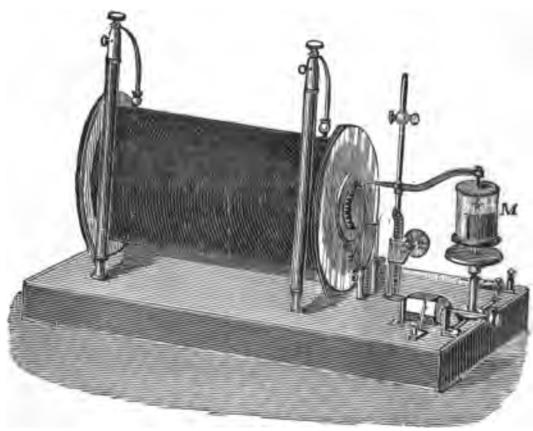


Fig. 68.

cuit in the primary coil is made an inverse current circulates in the secondary coils; and each time that the current is broken a direct current circulates. The latter induced current is the stronger of the two, for the reason that the current in the primary, on making the circuit, is retarded by the extra current, while that on closing is increased by the extra current. To render this inequality as great as possible a condenser is placed in the primary circuit. Whenever now the primary current is broken the extra current flows into it instead of jumping across the gap; and each time the current is again made this

stored-up electricity, which acts in a contrary direction to the current from the battery, adds to the effect of the extra current and weakens still more the strength of the primary current. When the two ends of the secondary wires are drawn apart the high electro-motive force of the induced currents will send a brilliant cascade of sparks across the interval. The length of the interval across

Fig. 69.

which the sparks can jump depends, of course, on the electro-motive force; and this, in turn, depends upon the strength of the primary current and the length of the fine wire of the secondary coil. Fig. 68 shows a mercury circuit-breaker at M, and Fig. 69 a mechanical circuit-breaker, by which the rapidity of the breaks is under the control of the operator, who turns the small crank shown at the right. On the left of Figure 69 is shown the luminous effects of the discharge in an exhausted glass vessel.

The induction-coil at the Stevens Institute at Hoboken, N. J., is said to have a secondary coil whose wire is fifty miles long. With three large bichromate cells sparks twenty-one inches long have been obtained. Mr. Spottiswoode's induction-coil is said to yield sparks forty-two inches long when worked by thirty Grove cells. The resistance of the secondary coil is about one hundred thousand ohms, and its length two hundred and eighty miles.

CHAPTER X.

ELECTRICAL MEASUREMENTS.

Galvanometers.—If we hold above and parallel to a compass-needle a wire through which a current is flowing, the needle will be deflected, as we have seen, in a direction and to an extent depending upon the strength and direction of the current. The direction of deflection, it will be remembered, can be predicted, if we bear in mind the following rule:

Suppose a man to be swimming with the current in the wire, and to be looking at the needle; then the north pole will be deflected towards his left.

Clearly, if we now bend the wire around the needle (Fig. 70), so that the current will run under it in the opposite direction, the left of the man still looking at the needle will be in the same direction, so that the effect of the lower turn will be added to that of the upper one. If we now pass the wire a second time over the needle the deflecting force will be still farther increased; so that if we keep winding a conductor round and round a compass-needle in the manner indicated in Fig. 71, we shall keep on increasing the deflecting force. Suppose that we then hang to the first needle a second one, pointing in the opposite direction (Fig. 72). This needle will weaken the force with which the first is held in the magnetic meridian; and if the wire runs below the

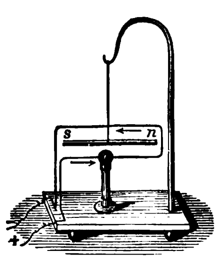


Fig 70

first needle and above the second needle, as shown in Fig. 72, the system will be very sensitive and will indicate the

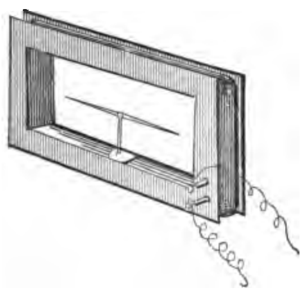


Fig. 71.

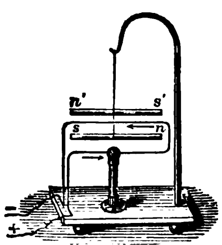


Fig. 72.

passage of very feeble currents. Such a system is said to be "astatic."

An apparatus consisting of a magnetized needle or a pair of astatic needles, around one of which is coiled a

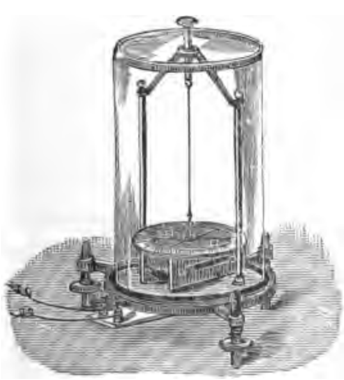


Fig. 73.

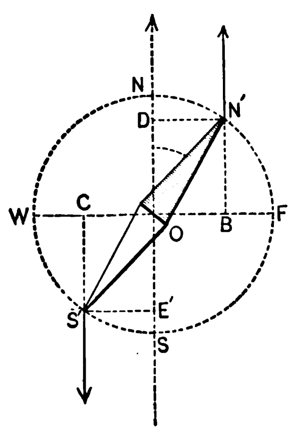


Fig. 74.

number of turns of wire, and which carries a dial whereon is indicated the angle of deflection of the needle, is called a "galvanometer" (Fig. 73). The relation of the

strength of current to the angle of deflection is deduced as follows:

Let N S (Fig. 74) represent the magnetic meridian and N′ O S′ a magnetic needle. Suppose it to be deflected to the position shown through the angle N O N′. The needle is now clearly acted upon by a "couple," which strives to pull each end back into the meridian, the strength of the couple being the product of the magnetic force at each end into the distance between them. Now, the force at each end is clearly the product of the earth's magnetic force into the strength of the pole. Representing this force by A, we have as the power of the couple

$$A \times BC.$$

But BC is twice the sine of the angle N O N′. Thus we see that *the force pulling a magnetic needle back into the meridian varies as the sine of the angle between the needle and the meridian.*

The Sine Galvanometer.—Upon this principle is based the "sine galvanometer." In this instrument the coils are supported on a vertical pivot. After the original deflection has been given the needle it will lie at such an angle to the coils as to be no longer influenced to the same extent as formerly, because the lines of force of the coils no longer act at right angles to the needle. The coils are then turned on the vertical pivot until they lie directly above the needle, when a greater deflection ensues. The coils are again moved, and ultimately a position of equilibrium is attained, the coils being directly over the needle, and holding it against the directive force of the earth. Then *the sine of the angle through which the coils have been turned is, on the above principle, proportional to the strength of the current.* A graduated circle is arranged below the vertical ring carrying the coils, from which can be read the angle through which the ring is turned. The relative strengths of two currents can therefore be ascertained

by discharging them both through the same sine galvanometer and noting the angles of deflection produced by each.

The Tangent Galvanometer (Fig. 75).—The tangent galvanometer is so constructed that its coils do not have to be rotated, and the strength of a current traversing it is reckoned, not from the sine of the angle of deflection produced, but from its tangent.

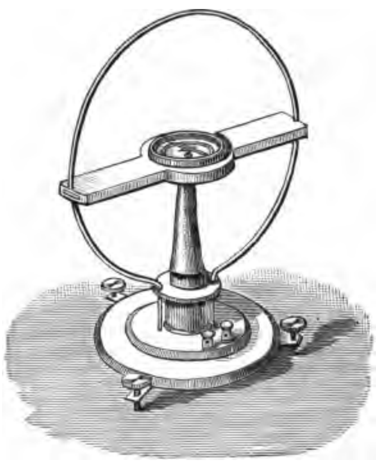


Fig. 75.

Principle of the Tangent Galvanometer.—As we have already seen, the magnetic force pulling a deflected needle back into the meridian is proportional to the sine of the angle through which the needle is deflected. In the case of a tangent galvanometer the deflecting force which opposes the magnetic force of the earth is perpendicular to the meridian, because the coils lie in the meridian. In other words, the couple produced by this force is equal to the couple produced by the magnetic force of the earth after the needle has been deflected to an angle at which equilibrium is established.

Therefore (see Fig. 74), letting A = the earth's magnetic force upon the needle, and A′ that of the coils,

$$A \times BC = A' \times DE', \text{ or}$$
$$A \times BO = A' \times DO;$$

therefore $$A' = A \times \frac{BO}{DO}$$

But $\frac{BO}{DO}$ = tan. NON′; therefore

$$A' = A \tan. NON'.$$

Therefore the tangent of the angle of deflection of a magnetic needle is proportional to the deflecting force acting at right angles to the meridian, and therefore to the current in the coils.

In order that the deflecting force of the current upon the needle may remain at a constant value, regardless of the angle of deflection, it is necessary that the coils should occupy such a position that the needle does not move appreciably outside of their plane. This is accomplished by making the coils very large and the needle relatively very small. In practice the coils usually consist of a few turns of very coarse copper wire. To avoid the necessity of referring to a table of tangents the scale is sometimes graduated so as to indicate the tangent of the angle of deflection, as shown in Fig. 76:

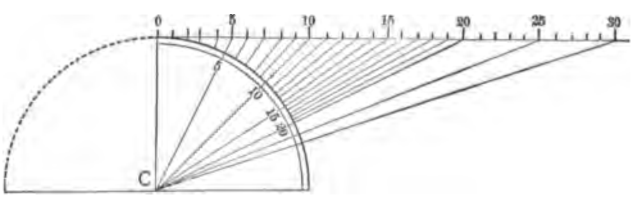


Fig. 76.

Differential Galvanometers.—In a differential galvanometer the needle is encircled by two separate and equal coils wound in opposite directions, so that if two equal currents pass each neutralizes the effect of the other upon the needle. In case, however, one current is stronger than the other, it deflects the needle in the same direction, though not to the same extent that it would did the other current not exist. As usually constructed the current, on entering the instrument, divides between the two coils, whose resistances are adjustable. Its use will be indicated farther on.

Sir Wm. Thomson's Mirror Galvanometer (Fig. 77).—This instrument is so delicate as to indicate

the existence and direction of currents much too feeble to affect the ordinary instruments, and is used to receive the signals sent through submarine cables. The needle is a very small magnet made of steel watch-spring, and is attached to a light concave mirror. The whole is suspended within the coils by a fibre of silk. Above the instrument is a curved magnet, so placed as to modify the

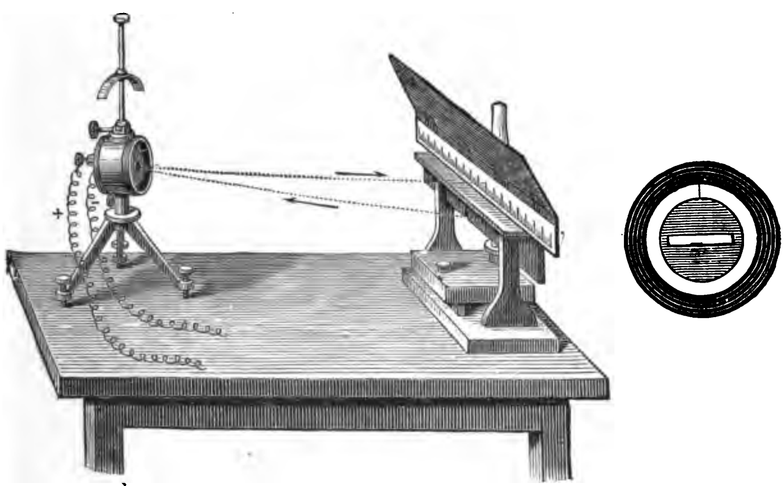


Fig 77.

effect upon the needle of the earth's magnetic force. A graduated scale stands opposite the galvanometer, and in this scale is cut a slit, through which pass the rays from a lamp placed behind it. The scale, lamp, and galvanometer are so placed that the rays of light fall upon the mirror, and are reflected back as a spot of light upon the zero-mark of the scale, which lies in the focus of the mirror. The feeblest imaginable current will be indicated by the motion of the spot of light in one direction or the other on the scale.

Marine Galvanometer.—A modification of this in-

strument, called the "marine galvanometer," is used on board ships employed in laying submarine cables. It is so constructed that neither the motion of the vessel nor any change of its course can alter the position of the spot of light on the scale. This is accomplished by attaching the magnet, *m*, Fig. 78, by a fibre to both the top and the bottom of the frame, C, the fibre passing exactly through the centre of gravity of both the needle and the mirror. The influence of terrestrial magnetism is neutralized by surrounding the coils with a permanent magnet, N S, whose influence on the needle overwhelms that of the earth.

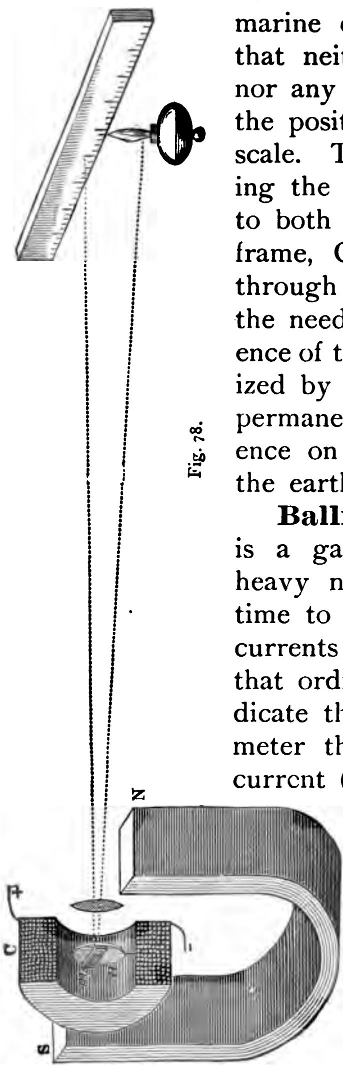


Fig. 78.

Ballistic Galvanometer.—This is a galvanometer with a long and heavy needle which requires a long time to swing, and is used to measure currents which last for so short a time that ordinary galvanometers cannot indicate them. In the ballistic galvanometer the effect of an instantaneous current (the discharge of a condenser, for instance) is delivered like a blow upon the needle, so that the force of the blow, or the quantity of electricity that passes through the coils in the instant, is proportional to the sine of half the angle of the first swing, in accordance with the law governing the swing of a pendulum when struck.

Ampère Meters, or Ammeters.—To measure the powerful currents used in electric lighting galvanometers as delicate as those hitherto described would not be suitable, so that special instruments have had to be devised. In most of these the directive force of the earth, not being sufficiently great, has been replaced by that of powerful magnets, and the needles are made exceedingly light. By these means oscillations of the needle are prevented

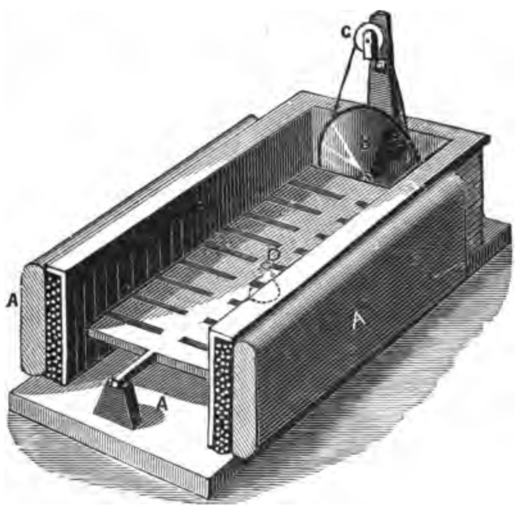


Fig. 79.

and the instruments made very dead-beat, so that the indications, even for very strong currents, may be read with ease. In most of them the instrument is so constructed, and the graduation is so made, that the angles of deflection, and not their tangents, are proportional to the strength of the currents. This is accomplished in various ways, as will be seen. As a representative of a practical type of ammeter, that of M. Marcel Deprez may be described.

The Deprez Ammeter.—In this instrument (Figs. 79 and 80) the magnetic field is produced by a power-

ful horseshoe magnet, and acts upon a "needle" in the shape of a wide, flat blade, cut into teeth, as shown. This needle, or blade, lies in fine bearings, and has upon its axis a large wheel, B, communicating by a little strap with a smaller wheel, C, carrying a light pointer, so that any oscillation of the blade is multiplied and indicated by the pointer. The needle, when at rest, lies in a horizontal plane, and a counterweight, D, on its under side steadies it. Around and inside the horseshoe magnet are two separate coils, one being of coarse wire and intended for strong currents, the other of fine wire and intended for

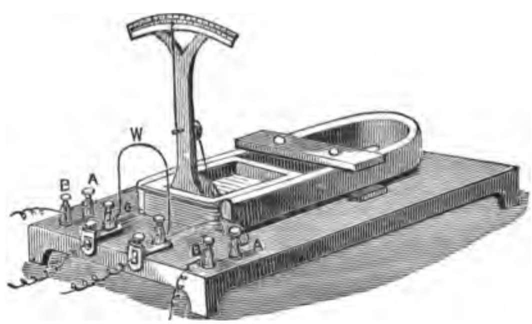


Fig. 80.

feeble currents. The deflections of the needle are usually multiplied by five by the belting, so that a deflection of the needle of five degrees is indicated by a deflection of twenty-five degrees of the pointer. As the tangents of small angles are very nearly proportional to the angles themselves, the indications of the pointer as high as fifty degrees may be considered, for practical purposes, proportional to the strength of current. Upon the front of the apparatus are three pairs of binding-posts, marked A, B, and C. The pair marked A communicate with the posts B, and are connected with the fine-wire coils. The terminals, C, connect with the coarse coils, which can be

short-circuited by a wire, W, if the whole current would be dangerous to the instrument. The dial indicates both volts and ampères, so that it can be used either as a " voltmeter," to measure the electro-motive force between two points, or as an ampère meter.

The way in which the graduation is effected for electro-motive force is as follows: Suppose we wish that one volt shall be indicated by a deflection of one degree. The current from a standard cell whose electro-motive force is constant, and whose internal resistance is small as compared with that of the fine-wire coil, is passed through this fine-wire coil, and resistances are then introduced until the pointer stands opposite the number of degrees upon the scale which equals the number of volts of electro-motive force of the cell. The deflection is, of course, proportional to the strength of current traversing the coils, but, at the same time, it is also practically proportional to the electro-motive force between the terminals of the cell; because, as the internal resistance of the cell is insignificant, the strength of current ($C = \frac{E}{R}$) is, for practical purposes, equal to the electro-motive force of the cell divided by the resistance of the fine wire, including the resistance we have added to it, so that we may consider the difference of potential between the binding-posts as that of the cell. The deflection obtained for this difference of potential or electro-motive force gives at once a basis for graduating. Consequently, if we afterwards pass any other current through the fine wire (adjusted to the resistance used in the above experiment) the number of degrees of deflection of the pointer will be the difference of potential between the points of the conductor attached to the terminals B.

To graduate for strength of current we pass through the large coil the current from a number of cells, so as to produce a pretty large deflection, and at the same time

we introduce a resistance such as to make the resistance of the circuit inside the instrument equal to one ohm. As $C = \frac{E}{R}$, and as $R = 1$, then the strength of current passing is equal to the difference of potential between the binding-posts. This difference of potential we can ascertain by attaching wires from them to the posts of another galvanometer, or voltmeter, previously graduated by the method just described. Ascertaining in this way the strength in ampères, we can mark opposite the deflected pointer the number indicating this, which gives at once the basis for graduating. If desired, however, we may modify this basis of graduation so that it shall correspond with that of the fine-wire coil. To do this we insert between the binding-posts the loop of coarse wire, W. As some of the current goes through this, the strength of current in the coarse coils will decrease and the pointer indicate a smaller deflection. To bring the pointer to the desired point on the scale we can change the size of wire, W, or insert it more or less deeply in the binding-posts, so as to increase or decrease the amount of current in the coarse coils, and the consequent deflection.

Ayrton and Perry's Ammeter and Voltmeter.—Another instrument which can be used as either an ammeter or a voltmeter is that invented by Professors Ayrton and Perry. In this ten coils encircling the needle are connected to a commutator, N (Fig. 81). By turning this commutator in one direction or the other the coils can be connected either in series or parallel. In the former case there will be ten times as many turns around the needle as in the latter case, and consequently any current will deflect the needle ten times as much; for the resistance of the coils is so small that whether they are in series or parallel does not sensibly affect the strength of current.

To graduate (or calibrate) the dial turn the commuta-

tor to series and send through the coils the current from a standard cell of constant E. M. F. Now take out the plug Y, thus adding a resistance of one ohm. Let the first deflection be A, the second A′. Then $A : A' = 1 + x : x$,

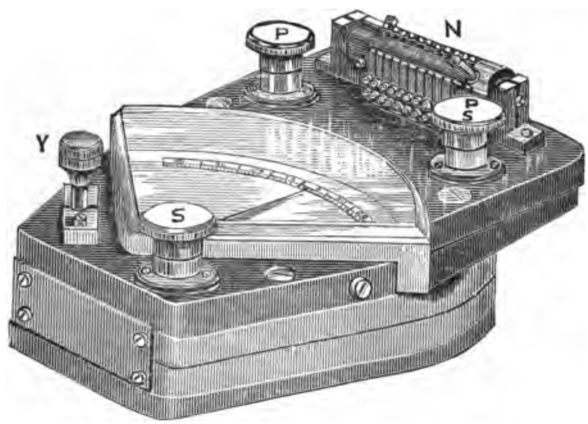


Fig. 81.

when x = the resistance of cell, leading wires, and instrument; then

$$Ax = A' + A'x, \; (A - A')x = A',$$

$$x = \frac{A'}{A - A'}.$$

Therefore the deflection A corresponds to a current $\frac{E}{\frac{A'}{A - A'}} = E\frac{A - A'}{A'}$ when the coils are in series, and, therefore, to a current $10\ E\ \frac{A - A'}{A'}$ when the coils are parallel. These give us at once a basis of graduation for both cases.

Usually, when strong currents are to be measured, the coils are placed parallel, and when feeble currents are to be measured, in series; because it is not well to subject a

magnetic needle to too powerful magnetic influences, and feeble currents passing through the parallel coils could not exert a sufficiently strong deflecting force on the needle.

To make it impossible to pass a very powerful current, like an electric-light current, through the coils when in series, the binding-screws P P are not connected with them, except when the commutator is turned to parallel. The screws S S, on the other hand, are not in their circuit, except when the commutator is turned to series. Ayrton and Perry's voltmeter is constructed on nearly the same principle. To calibrate this the commutator is turned to parallel and a current sent through from a standard cell. Let the resistance of each coil be 10 a; then the resistance of all in series will be 100 a, and that of all in parallel will be a. The instrument bears a plug in the parallel circuit, short-circuiting a resistance-coil of this resistance a. Suppose the first deflection to be A. Now take out the plug, introducing the resistance a, and suppose the new deflection to be A′. Let x = resistance of instrument, wires, and cell; then,

$$A : A' = a + x : x,$$

$$A'(a + x) = Ax, \ (A - A')x = A'a,$$

$$x = \frac{A'a}{A - A'}.$$

Therefore the deflection A was produced by a current

$$\frac{E}{\dfrac{A'a}{A - A'}} = \frac{E(A - A')}{A'a}.$$

Now, as the resistance of the instrument with the coils *in parallel* is a, and as $E = CR$, the difference of potential between the binding-posts for the deflection A must have been

$$\frac{E(A-A')}{A'a} \times a = \frac{E(A-A')}{A'};$$

and therefore as *in series* the resistance is 100 a (a being much larger in this instrument than in the preceding), but the number of turns is multiplied by 10, the difference of potential would be, for a deflection A,

$$\frac{10E\,(A-A')}{A'},$$

which give a basis for graduation for both cases.

Spring Ammeter and Voltmeter.—As every

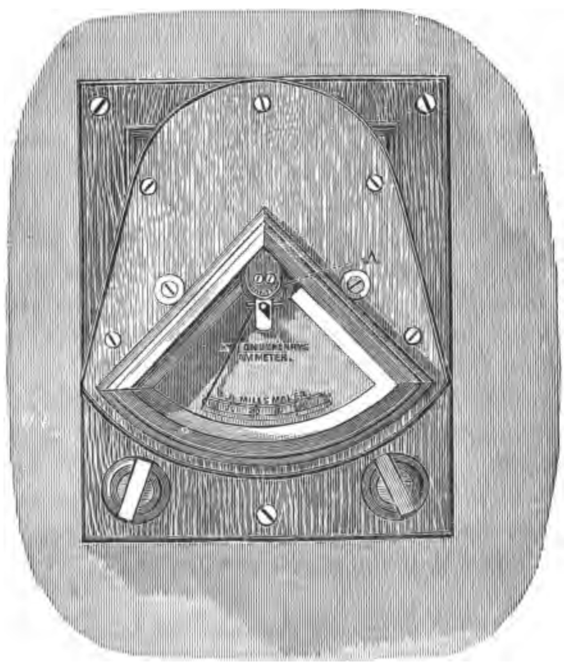


Fig. 82.

steel magnet loses more or less magnetism in time, and as the indications depend upon the relative directive forces of the magnet and the currents, it is clear that such a loss must introduce elements of inaccuracy. To overcome this trouble Professors Ayrton and Perry have devised a

spring ammeter and voltmeter, in which the directive force of the horseshoe magnet is replaced by that of a spring, against which the current exerts its deflecting power. Fig. 82 represents a spring ammeter, the spring being represented by the spiral, A. The needle is so inclined to the direction of the coils that its angles of deflection as high as forty-five degrees are, for practical purposes, proportional to the strength of the current. The instrument can be so regulated by turning the spring through a certain angle, for which there is a scale engraved on the dial beneath it, that the needle will not start from zero until the strength of the current in the ammeter, or its E. M. F. in the voltmeter, has passed a predetermined point. Thus the instrument can be given different degrees of sensibility. If, for instance, we wish to measure a current which we know to be greater than twenty-five ampères, we set the spring so that the needle will not leave zero until a strength of twenty-five ampères has been reached. Now, if the needle started from zero with a very feeble current, we should have only, say, one division to indicate a difference of one ampère. But if it does not start unless a strength of twenty-five ampères is attained, then the whole succeeding angle of forty-five degrees can be used to indicate an increase of, say, ten ampères beyond the twenty-five, or four and a half per ampère, by decreasing the tension of the spring. In other words, we can thus increase the sensibility four and a half times.

Wheel and Pinion Ammeter and Voltmeter.—Where still greater sensibility is needed a multiplying arrangement is connected with the needle. This is very similar to that used in aneroid barometers. A sector of a wheel with very fine teeth is attached to the arbor of the needle (Fig. 83), and gears into a pinion having a much smaller radius, to which pinion is attached a long pointer. If the ratios of the radii are ten to one, the deflection of

the needle will be multiplied by ten; so that if we have an ammeter in which the deflections of the needle as high as thirty-six degrees are proportional to the strength of current, the pointer will have the whole circumference of the dial upon which to give its indications.

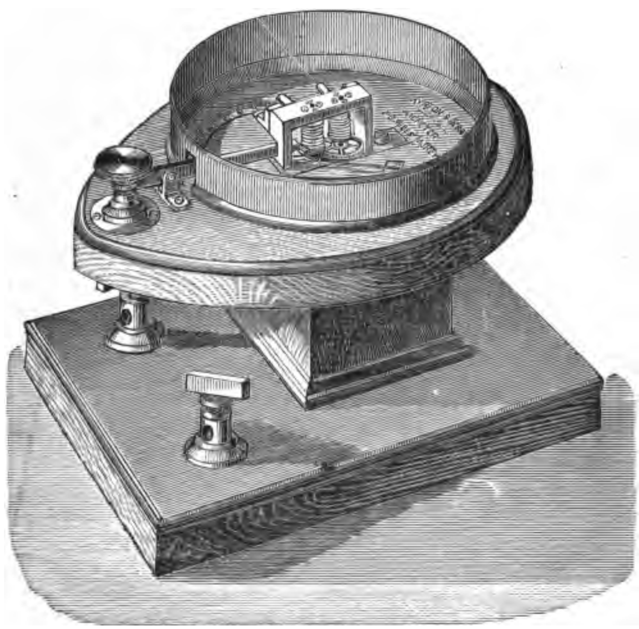


Fig. 83.

Voltameters.—It will be remembered that, in speaking of batteries, we found that galvanic currents were weakened by the opposing force of polarization, due primarily to the electrolyzing action of the current upon the solution. The decomposing power of the current can be used to measure its strength and quantity, and the instrument for so measuring it is called a "voltameter." A voltameter, it must be noticed, however, is different from a galvanometer, not only in the principle of its action, but

in the thing indicated; for a galvanometer gives an instantaneous indication of the strength of a current—that is, of the number of units of current passing per second—while a voltameter adds up all the units of current that pass during any interval, and registers their sum. If desired the average strength of current during the interval can then be calculated by dividing the number of units by the number of seconds.

A simple voltameter can be made as shown in Fig. 84, in which a bent tube leads from the jar containing the two electrodes into a graduated inverted tube filled with water. When the circuit is closed the oxygen and hydrogen evolved rise in this tube, and their amount is indicated by the scale. Knowing the amount of the two gases (.176 cubic centimetres) liberated by one coulomb, we can thus ascertain the number of coulombs which have passed.

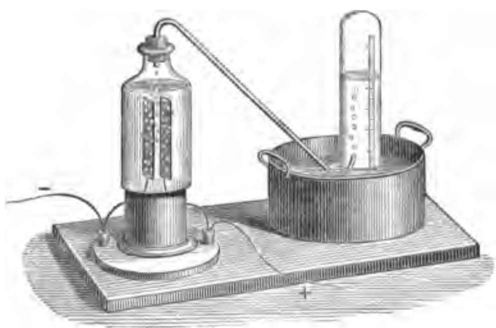


Fig. 84.

Zinc Voltameters.—If we place two electrodes of zinc in a solution of sulphate of zinc, and send a current between them, zinc will be added to the cathode and subtracted from the anode. Knowing that one coulomb deposits .0003412 grammes of zinc, we can, by measuring the amount by which one of the electrodes gains or loses weight, calculate directly the number of coulombs which have passed.

Measurement of Electrical Resistance.—1. Knowing from Ohm's law that the strength of current in a circuit is inversely proportional to the resistance, we

can measure the resistance of any conductor in the following way: Put the conductor in circuit with a battery and a galvanometer, and note the deflection of the pointer. Then remove the conductor, and substitute in its place wires whose resistances are known, until one is found through which the battery produces the same deflection as through the other. The resistance of this wire must clearly be equal to that of the conductor.

2. If a tangent or a sine galvanometer is used it will not be necessary to find a wire through which the battery will produce the same deflection; because as the tangents (or sines, as the case may be) of angles of deflection are proportional to the strength of current, and as the strength is inversely proportional to the resistance,

$$\text{tan. } a : \text{tan. } a' = r' : r,$$

$$r = \frac{\text{tan. } a' \times r'}{\text{tan. } a};$$

or,

$$\text{sin. } a : \text{sin. } a' = r' : r,$$

$$r = \frac{\text{sin. } a' \times r'}{\text{sin. } a}$$

in which r is the resistance sought, and r' the resistance known.

3. With a differential galvanometer the operation is simplified. In using this instrument it is only necessary to insert the unknown resistance in the circuit of one coil, and a number of known resistances in the circuit of the other. As the coils are similar in all respects, the needle will obey the stronger current—*i.e.*, that in the branch containing the least resistance. Insert now known resistances until the needle gives no deflection when the circuit-closing key is pressed. The currents in both coils must now be equal; in other words, the resistances in both branches must be equal, so that the resistance sought is equal to the known resistance introduced.

Wheatstone's Bridge.—Another and still more accurate method is Wheatstone's bridge method.

It will be remembered that the cause of the movement of electricity through a conductor is the difference of potential at different parts of the conductor, which causes an electro-motive force—*i.e.*, a force tending to move electricity against the resistances of the conductor. Now, as it requires a difference of potential to enable an electric current to overcome resistance, it follows that it requires more difference of potential to overcome a great resistance than a small one in any circuit. Therefore, if we have a conductor made up of materials which differ in conductivity, or if it is made of different thicknesses, or if it is divided into sections of varying length, there will be a greater fall of potential between points separated by a great resistance than between points separated by a small resistance. In a wire of uniform material and section, however, the fall of potential will be uniform. By using an electrometer like that of Sir William Thomson, and testing the potentials of different points along the wire, the phenomenon of fall of potential can be conveniently observed.

The equality of the fall of potential over equal resistances is the principle of Wheatstone's bridge. Suppose that the current of the battery, E, divides at 1 into two branches, as represented in Fig. 85, which reunite at 2. Then the fall of potential between 1 and 2 will bear the same ratio to the electro-motive force of the battery that the joint resistance of the two branches

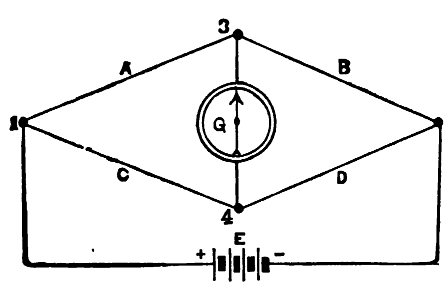


Fig. 85.

bears to the resistance of the whole circuit. But as 1 and 2 have each a certain definite potential, the fall of potential along 1, 4, 2 is exactly as great as that along 1, 3, 2, no matter what are their respective resistances; so that if 4 and 3 are so placed that the resistance A has the same ratio to B that C has to D, their potentials will be equal, so that if they are joined by a conductor, or "bridge," 3, 4, no current will pass between them. If, however, they are not so placed—that is, if the resistances in the arms do not bear the ratio indicated—then the points 3 and 4 will not have the same potential, so that if joined by a conductor, or "bridge," including a galvanometer, a current will pass from the one having the higher potential, and will be indicated by a deflection of the galvanometer.

A convenient form of Wheatstone's bridge is constructed by making the arms A and C of equal resistance, placing an adjustable resistance in D and the resistance to

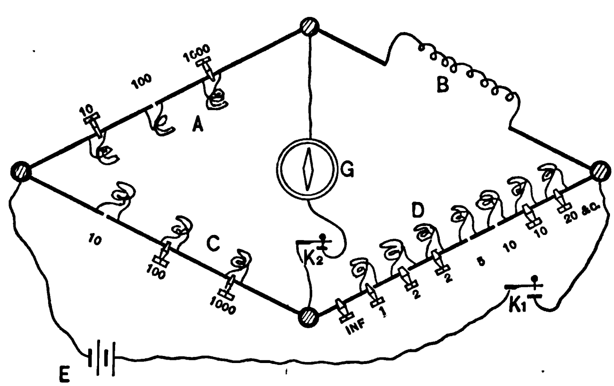


Fig. 86.

be measured in B. The resistance in D is then adjusted until the galvanometer gives no deflection, whether the circuit-closing key is pressed or not, when the resistance sought must be equal to the known resistance introduced in D.

In case the resistances in A and C are not equal, but have the ratio $\frac{C}{A} = n$, then, when the galvanometer shows no deflection, $\frac{D}{B} = n$, therefore $B = \frac{D}{n}$. The resistances in A and C are usually made adjustable, also, by means of resistance-coils, so as to give greater flexibility and scope to the instrument (Fig. 86).

Rheostats, or Resistance-Coils.—A rheostat consists of a number of coils of wire the resistances of which have been carefully determined. The coils are usually made of German silver, because the heating effect of the current upon German silver does not alter its resistance. They are usually wound double, as shown in Fig. 87, in order that each length may neutralize the effects in the other of extra currents on making and breaking the circuit. The wires are, of course, insulated; for otherwise the turns where they cross would furnish short circuits for the current. Each end of each coil is soldered to a metal piece, the metal pieces A, B, C, etc., being separated by air-spaces, which can be filled with brass plugs, D, E, etc., so as to short-circuit or bridge over the resistance-coils. The resistance of each coil is marked on the top of the resistance-box (Fig. 88), so that by taking out any plug the resistance marked opposite to that plug is introduced into the circuit. Ordinarily the coils are so ar-

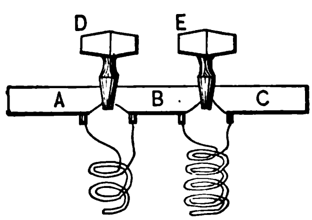


Fig. 87.

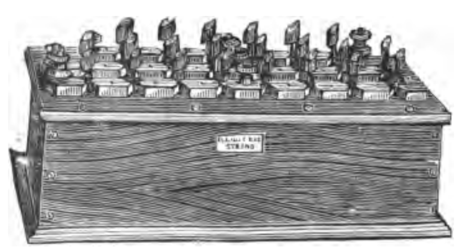


Fig. 88.

ranged that any resistance from one-tenth ohm to ten thousand ohms may be introduced. Fig. 86 shows a Wheatstone bridge with a rheostat in each arm, except in B, in which the resistance to be measured is placed. As, when equilibrium occurs, $\frac{A}{C} = \frac{B}{D}$, we can obtain indications of fractional resistances by suitably adjusting the resistances in A and C. Suppose, for instance, that we know the resistance sought to be very small, but do not know exactly how small it is. We can make the resistance of C one thousand ohms and that of A ten ohms. Suppose that after inserting the unknown resistance the needle gave no deflection when we had introduced a resistance of one hundred and twenty-five ohms in D. Then,

$$n = \frac{C}{A} = 100,\ B = \frac{D}{100} = \frac{125}{100} = 1.25.$$

Battery Measurements; Internal Resistance. —1. To measure the internal resistance of a battery put the battery in the arm B of a Wheatstone bridge, and put a key in the circuit where the battery was. Adjust the resistances in the arms until the deflection of the galvanometer is the same when the key is depressed as when it is open. Then the battery resistance is balanced by that of the other arms. In this case, it will be noticed, we do not look for a zero deflection, because the point 3, nearer to the positive pole, must be at a higher potential than 4. The effect of depressing the key is merely to reduce the resistance of the circuit from 2 to 1, and therefore to raise the potential of 1 and therefore of 4. But if the resistances in the four arms balance, the potential of 3 is raised as much as that of 4, so that the deflection of the galvanometer is not altered.

2. Another way is to put two equal cells in the arm of a bridge, united so that their currents flow in opposite directions and thus neutralize each other. Their added

resistances may now be measured undisturbed by the effects of their currents, just as is the resistance of a conductor, and then halved to give the resistance of one. If we join the cells in the manner named it is clear that, if desired, we can measure their resistance in other ways than by using a Wheatstone bridge.

Measurement of Electro-motive Force.—To measure the electro-motive force of a battery the best way is to compare it with that of a cell whose electro-motive force is known. A Daniell cell whose E. M. F. is 1.079, and which is quite constant, is ordinarily used.

1. Leave the circuit of the cell open, and measure the difference of potential of the two poles by Sir William Thomson's quadrant electrometer. Multiply the number indicating the difference of potential by 2.93×10^{10}, and divide by 10^8. The multiplication reduces the indication from electro-static to electro-magnetic units, and the division reduces the electro-magnetic units to practical units.

2. Another way is to join the standard cell with a galvanometer and note the deflection. Suppose it is a degrees. Now introduce a resistance r and note the deflection—say b degrees. Then substitute the battery whose E. M. F. we wish to find, and introduce a resistance until the deflection a is reproduced, and then add a resistance r' until the deflection b degrees is reproduced. Then, since the resistance r with an electro-motive force E has caused the same deflection $(a - b)$ as the resistance r' with an electro-motive force E′,

$$\frac{E}{r} = \frac{E'}{r'}, \text{ therefore } E' = \frac{Er'}{r}.$$

Measurement of Capacity.—For many purposes of telegraphy it is necessary to know the capacity of a condenser—that is, the number of units of electricity which it can hold before being raised to a potential of one. The measurement is usually effected by comparing

the capacity of the given condenser with that of a standard condenser whose capacity is known. This may be done in several ways:

1. Charge the two condensers to the same differences of potential, and then discharge each in succession through a ballistic galvanometer, noting the deflection caused by each. Then, as the force of the blow is proportional to the sine of half the angle of the first swing, and as the two condensers are at the same potential, their charges, and therefore their capacities, are proportional also to the sine of half the angle of the first swing in each case.

2. Put the two condensers in two branches connected with the same pole of the same battery, and adjust resistances in those branches until the potentials in the two condensers advance at equal rates. Then the capacities must be inversely as these resistances, because they are directly as the currents.

3. Charge the condenser to a certain potential, p; connect it with a standard condenser, so that it will share with it some of its charge. Measure the resulting potential, p'. Let a = capacity of the standard condenser, and x that of the condenser whose capacity is to be found. Then $a + x$ = their joint capacity. Let p = first potential and p' the second. Then, as the number of units of electricity is equal to the capacity multiplied by the potential,

$$x \times p = (a + x)\,p',$$

$$x\,(p - p') = ap',$$

$$x = \frac{ap'}{p - p'}.$$

CHAPTER XI.

TELEGRAPHY.

TELEGRAPHY may be defined as the art of producing signals at a distant point by means of the action of an electric current upon electro-magnetic apparatus. At the sending station a key of the general form shown in Fig. 89 is placed, which, when depressed, closes the circuit and

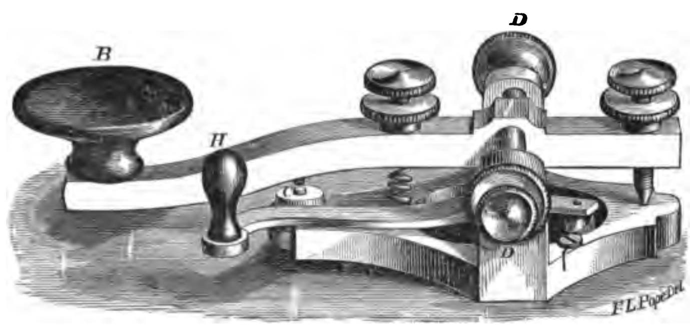


Fig. 89.

allows the electric current to pass to the electro-magnet at the receiving station. This electro-magnet, being thus magnetized, attracts its soft-iron armature, which strikes it sharply, thereby producing a very audible "click." Each letter of the alphabet is made by opening and closing the circuit a certain number of times and for periods of varying duration; and, as the armature of the electro-magnet responds to the motions of the key, a practised ear can detect, from the duration and succession of the clicks, each letter as it is made. In this country the fol-

lowing alphabet of Prof. Morse is used, a dot being produced by closing the circuit for a short interval, and the dash by closing it for a more protracted interval:

I. Alphabet.

A	·—	O	· ·
B	—···	P	·····
C	·· ·	Q	··—·
D	—··	R	· ··
E	·	S	···
F	·—·	T	—
G	——·	U	··—
H	····	V	···—
I	··	W	·——
J	—·—·	X	·—··
K	—·—	Y	·· ··
L	⸺	Z	··· ·
M	——	&	· ···
N	—·		

II. Numerals.

1	·——·	6	······
2	··—··	7	——··
3	···—·	8	—····
4	····—	9	—··—
5	———	0	⸺

III. Punctuation, etc.

Period	··——··	Exclamation	———·
Comma	·—·—	Parenthesis	·····—·
Semicolon	··—·—	Italics	··—·—
Interrogation	—··—·	Paragraph	————

Upon the closed-circuit system a number of stations are placed upon one circuit, and when no message is passing along the line the current is circulating through all of them. On each key is a switch, H, which on being turned

in one direction or the other breaks the circuit or closes it. The action of the electro-magnet at each station is, however, merely to close the local circuit, which operates another electro-magnet placed upon a resonant sounding base. This electro-magnet with its sounding base is termed a "sounder."

Letting Fig. 90 represent a closed circuit, the current

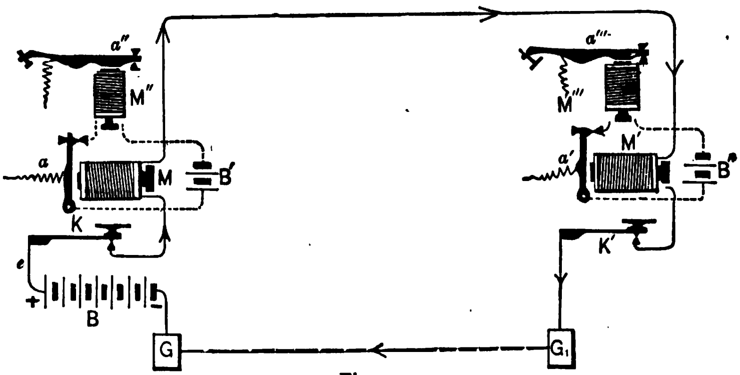


Fig. 90.

passing from the positive pole of the battery, through the key K, whose switch is closed, through the electro-magnet M, the line-wire, the electro-magnet M′ at the receiving end and the key K′, whose switch is closed, to the ground G′; the negative pole of the battery being connected to the ground at G. It will be noticed that only one wire is used. The reason for this is that for the small currents used in telegraphy the earth can act as a very good return conductor, the circuit being completed between the earth-plate sunk in the earth at G′ and one sunk in the earth at G. In this way we get a conductor for the return current costing nothing, and offering much less resistance than a wire.

Now, the current, in passing through the electro-magnets M and M′, magnetizes them, so that they attract their

armatures, a and a'. This brings the armatures down upon contact-points, thereby closing the circuits of the local batteries, B′ and B″, magnetizing the electro-magnets M″ and M‴, which attract their armatures, and, being placed upon sounding bases, give out, therefore, very audible clicks. The current remaining closed, the armatures rest quietly in this position. Suppose now that the operator at A desires to signal to the operator at B. He first throws his switch to the right, thereby breaking the circuit and liberating the armatures a and a', a'' and a''', and any similar armatures along the whole line. He now begins to close and open the circuit by manipulating his key, thereby operating all the sounders along the line, his own included. If now the operator at B, who has been called by A by a preconcerted signal, fails to understand what A is telegraphing, or if he wishes to signal something to A, he moves his switch to the right, thereby breaking the circuit. A's sounder will not now act; so A knows that something is wrong. He therefore moves his switch to the left and waits for a signal.

The Sounder is shown in Fig. 91. It is mounted

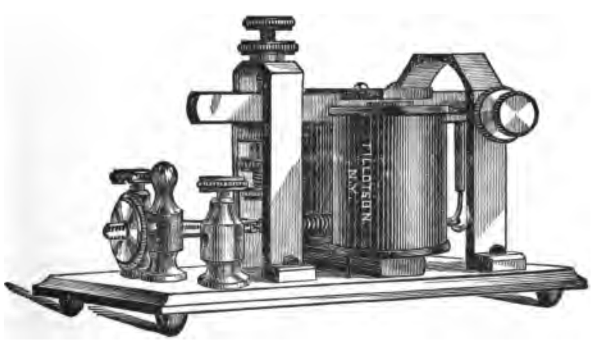


Fig. 91.

upon a resonant base having metallic feet at each end, the electro-magnet being covered with a polished casing of

vulcanized rubber. It is operated, as has been said, by a small local battery at the station.

Relay.—The receiving magnet, or relay, consists of an electro-magnet and armature, so arranged that when the main circuit circulating through the electro-magnet causes it to attract the armature, this armature closes the circuit of a local battery, which operates the sounder. A form of relay is shown in Fig. 92. In front of the

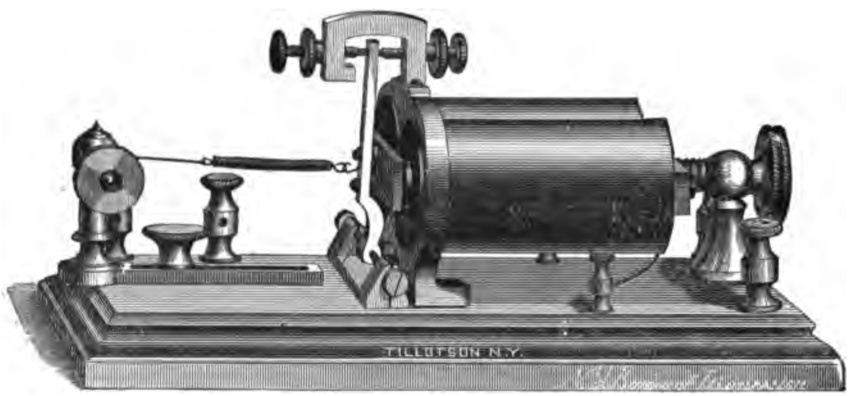


Fig. 92.

poles of the electro-magnet is the soft-iron armature, connected with one pole of a battery, and arranged, when attracted, to strike against a stop connected to the other pole of the battery. In order to adjust the relay to currents of different strength, the retractile spring shown is made adjustable in tension. It is connected at the end near the left of the instrument to a cord, which passes around an axis terminating in the milled head; so that by turning this head in one direction or the other the tension of the spring is increased or diminished.

Polarized Relay.—A modification of the ordinary, or Morse, relay is found in the polarized relay, in which no retractile spring is required, the motion of the ar-

mature being produced by the alternate attraction of two magnet-poles. The construction is represented in Fig. 93. The permanent steel magnet, N S (Fig. 93), is given the form shown, and two electro-magnets, *m* and *n*, are placed upon the lower or N pole (Fig. 94); a

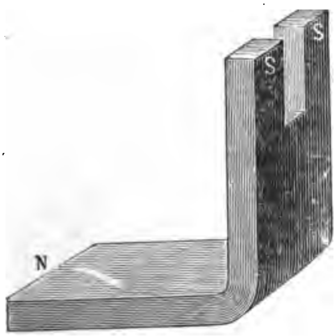


Fig. 93.

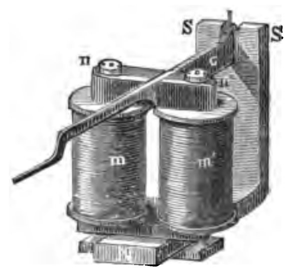


Fig. 94.

soft-iron armature is pivoted at the S pole, and extends between the two pole-pieces of the electro-magnets, as shown.

This armature is made to lie a little closer to one pole than the other; let us suppose that it lies closer to the pole of *n* (Fig. 95). Now, the soft-iron armature is magnetized by the south pole, S, with which it is in contact, while the soft-iron cores of both electro-magnets are, when no current is passing around them, magnetized by the north pole, N, with which they are in contact. Therefore the pole-pieces of both attract the armature; but, as it is placed nearer *n*, the attraction of *n* prevails, and it is pulled over to *n*. Now, the coils are so wound that, when a current passes, *n* becomes a south pole and *n'* a north pole; *n'* then attracts the armature, which immediately starts towards it, but brings up against a stop, D', in the circuit with a local battery and sounder; so that the local circuit is thus closed and the sounder operated. As soon as the current ceases

the polarity of both cores immediately becomes that of N, and, as the armature has not been allowed to move

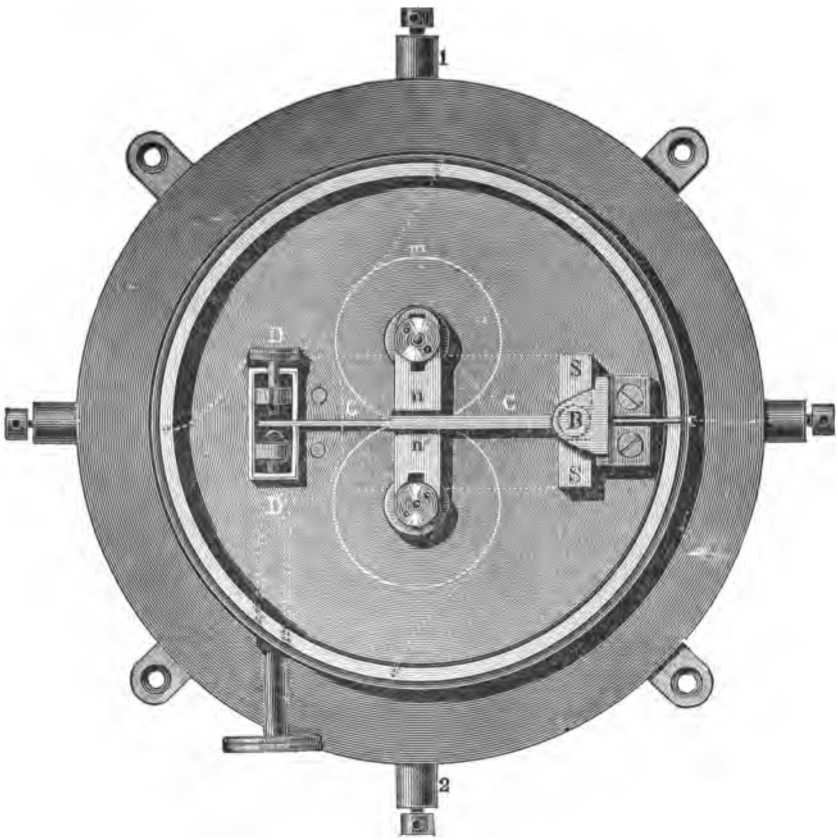


Fig. 95.

half the distance from n to n', the attraction of n prevails over that of n', and the armature is attracted back again to n, thus leaving the contact-point D' and breaking the circuit of the local battery. In practice, however, this relay

is ordinarily used with alternating currents—that is, currents which flow first in one direction and then in the other. In flowing in one direction, for instance, the current makes n a north pole and n' a south pole, so that the armature is attracted by n; while when flowing in the other direction it makes n a south pole and n' a north pole, so that the armature is attracted by n'. We see that by this system the current is not made and broken, but that it constantly flows, though in alternate directions, over the line.

The polarized armature is used not only in telegraphy, but in very many kinds of electrical apparatus.

The Key.—Fig. 89 gives a view of one form of telegraph key. The frame is screwed firmly to the table, and the key is pivoted about the axis, D. One wire of the main circuit is secured to the metallic frame, and the other to the anvil, C, which is insulated from the frame. The knob, B, is of hard rubber or other insulating material. Beneath the key is a platinum stud, which, when the key is depressed, comes into contact with a similar platinum stud on the anvil—platinum being used on account of its infusible nature, which saves it from being oxidized by the spark due to the extra current on breaking. The switch, H, when pulled to the left, bridges over the distance between the anvil and the frame, thus keeping the circuit closed.

The Register.—This is an apparatus for automatically recording the signals received, and is used more in Europe than in the United States, though it was at one time used to a considerable extent in this country also. The arrangement of the electro-magnet and armature seen to the right of Fig. 96 will be understood from what has been already said. It only remains to add that the armature is prolonged to the left beyond the pivot, and ends in a stylus, as shown, which, therefore, rises as the armature is attracted. In rising it comes up into contact with

a strip of paper drawn along under the stylus by clockwork actuated by springs or weights. The paper being drawn along at a uniform rate, a current of long duration, or a dash, will clearly occasion a long mark upon the paper, whereas a current of short duration, or a dot, will occasion a short mark upon the paper. In this way, then, the messages are recorded upon the paper strip in a suc-

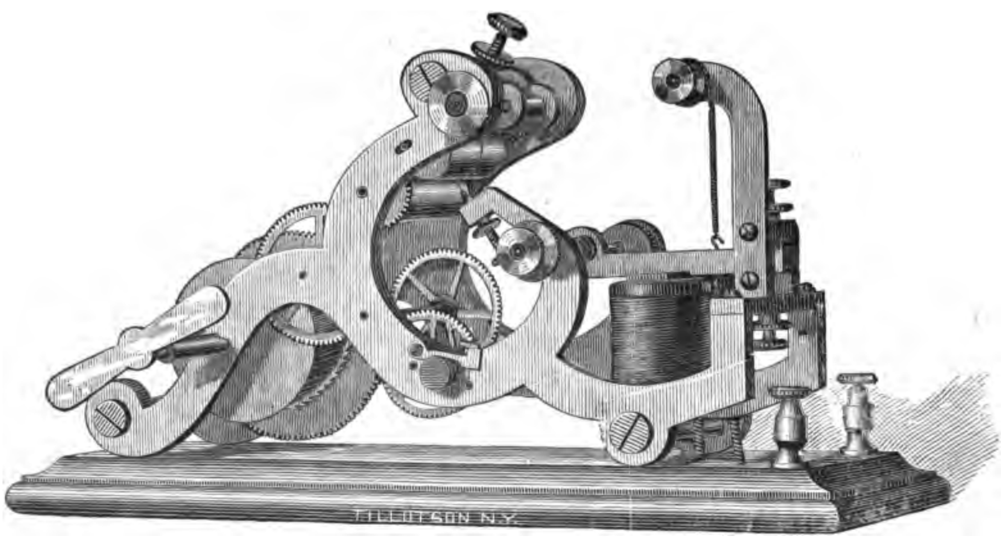


Fig. 96.

cession of dots and dashes, which correspond to the dots and dashes signalled from the sending end, and which can be read off and translated into ordinary language.

Multiplex Telegraphy.—By this term is meant the art of sending a number of messages over the same wire at the same time. To express the sending of two messages the term "duplex" is ordinarily employed, and to express the sending of four messages the term "quadruplex."

Duplex Systems.—The simplest system for sending two messages in opposite directions at the same time is that known as the bridge method. In this method the receiving apparatus at each end is put in a "bridge," of which the arms have such a ratio that the points at the top and bottom have the same potential as regards currents coming from the battery at that place; so that no current traverses the receiving apparatus, no matter whether the current is closed or not. If, for instance, the ratio of the resistance in *a*, Fig. 97, is to the resistance in *b* as the resistance of the line is to that of the artificial resistance P, then no current coming from the battery B will go through the relay M. The current will, however, traverse the line, and, on getting to C, will divide, part going through C D to ground, and part through the relay M′ and thence to ground. If at the same time a current is sent from D, this current will not act on its own relay placed in the bridge at that place, but will neutralize the current coming from the opposite direction. F will, therefore, now receive a current, because the equilibrium of potential in the arms *a* and *b* is destroyed. Thus, under any circumstances, the relay in the bridge at each end will respond to the depressions of the key at the other end, but will not respond to the depressions of the key at the same end. If we wish to send simultaneously two messages in the *same* direction, one of the simplest arrangements we can use is that invented by Mr. Edison. At the sending end are two different kinds of keys, one of which serves to reverse the direction of the current when depressed, the other to increase and diminish it. At the

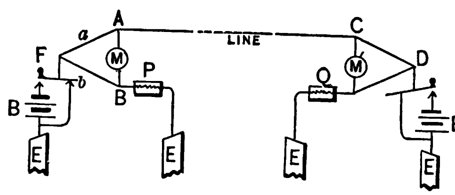


Fig. 97.

receiving end are two different relays, one of which, having a polarized armature, responds only when the direction of the current is reversed; the other, having a soft-iron armature, responds only when the current is so increased that the tension of its retractile spring is overcome. By this plan it is evident that the polarized relay responds when the first key is depressed, and remains silent when the second key is depressed; and that the other relay responds when the second key is depressed, and ignores the movements of the first key. Systems for sending two messages simultaneously in the same direction are sometimes called "diplex," and those for sending them in opposite directions "contraplex."

Quadruplex Systems.—These combine both diplex and contraplex systems. At each end are two keys, one of which is arranged to change the direction of the current, and the other to increase and decrease it; and two relays, placed in a "bridge," one arranged to respond to reversals of the current, the other to increments and decrements in strength, the tension of its retractile spring being so adjusted that the strength of the electro-magnet will not be sufficient to overcome it until the current is increased to a certain strength. Neither relay responds to currents coming from the battery at the same end; so that four separate currents can, by this method, be sent over the wire at the same time without interfering with each other.

Harmonic Telegraphy.—Among the most recent methods of multiple telegraphy introduced into practice is the harmonic, or musical, system.

It is a well-known fact that if we strike a tuning-fork it will emit the same note, no matter whether we strike it gently or violently; and that it will emit this note also if that note be sounded by some external source, such as a piano, by reason of the impact upon the tuning-fork of the vibrations of air set up by that source. But if any

other note be sounded the tuning-fork will remain silent; though if we have at hand another tuning-fork which, when struck, will emit the note we have just sounded, then this tuning-fork will immediately respond.

If, therefore, we have a number of tuning-forks of different shapes and sizes, so that they vibrate at different rates and emit different tones, and if we then play a tune upon a musical instrument, each tuning-fork will pick out its own note whenever it is sounded, and respond in unison.

Harmonic telegraphy may be briefly described as a system by which a number of tuning-forks are so connected electrically with the same number of like tuning-forks that each tuning-fork at the receiving station emits its peculiar note whenever the corresponding tuning-fork at the sending station is set in vibration.

In place of tuning-forks steel reeds are used, which are mounted in front of electro-magnets, like armatures. It will be remembered that, in speaking of electric bells, the armature was described as acting as an automatic circuit-breaker, breaking the circuit whenever attracted towards the electro-magnet, and re-establishing it whenever its retractile spring drew it back. The steel reeds used in harmonic telegraphy are similarly mounted; and as, from its shape and size, each can vibrate only at the rate depending upon that shape and size, each will, whenever the key is depressed and a current sent through the electro-magnet, break and close the circuit as many times per second as it would vibrate per second if struck. Suppose the reed shown in Fig. 98 to vibrate one hundred times per second, and to be mounted as an armature before an electro-magnet which is in the circuit with a precisely similar electro-magnet and armature, *m*, at a distant station. When now the circuit-closing key is depressed, the electro-magnet *m* at the receiving station will be magnetized and demagnetized one hundred times per second, so that its armature will be attracted and drawn away from it

one hundred times per second. But the armature is of such a size and shape that, when it has been once attracted and withdrawn by the retractile force of its own elasticity, it is about to vibrate again towards the electro-magnet just as the attracting force of the electro-magnet again operates. The reed is then thrown into vibration, in the same way that a swing is when we give it successive impulses, just at the times when it is beginning to swing in the direction of the impulses. Thus we see that both reeds are thrown into similar vibrations, and therefore emit the same musical note, each time the key is depressed. But suppose there is in the same circuit another electro-magnet, *m'*, whose armature is of such a size and shape that it can vibrate only at the rate of one hundred and fifty times per second. This electro-magnet will also be magnetized and demagnetized one hundred times per second, but the armature will not be thrown into vibration, because it is subjected to a succession of attractions which do not occur at times when it is ready to move in the direction of the attraction. The effect is the same as we would produce if we gave a succession of impulses to a swing at improperly-timed intervals. The armature will therefore ignore all impulses sent by the key. But suppose that we had at the sending station another key, adapted to send currents through an electro-magnet at the sending station whose armature is a steel reed of such size and shape that it breaks the circuit one hundred and fifty times per second. Then, when this key is depressed, the armature of *m'* will vibrate and that of *m* remain silent.

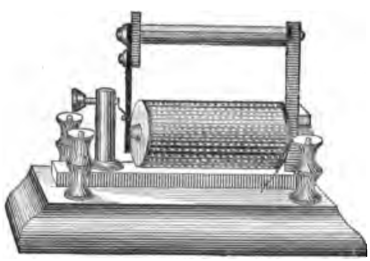


Fig. 98.

Consequently, if we have at the sending station a num-

ber of electro-magnets with armatures capable of different rates of vibration, connected electrically with the same number of similar reeds, each reed at the receiving station will vibrate, and therefore emit its peculiar note, whenever its corresponding reed vibrates at the sending station. It is only necessary, therefore, for each operator at the sending end to manipulate his key as in sending a despatch by the ordinary system. The armature of each will respond at each depression of the key, not with a sharp click, but with the hum of its peculiar note, and at the same time the corresponding armature at the receiving station will respond, each one following the dots and dashes of its mate at the sending end and disregarding all the others.

Speed of Signalling.—It is not possible, however, to signal through a long line with the same speed that can be attained in signalling through a short one. The principal cause which operates against great rapidity is that due to what is called "retardation," which is more marked in submarine and subterranean lines than in aerial ones.

Retardation; Electro-static Charge (Fig. 99).—

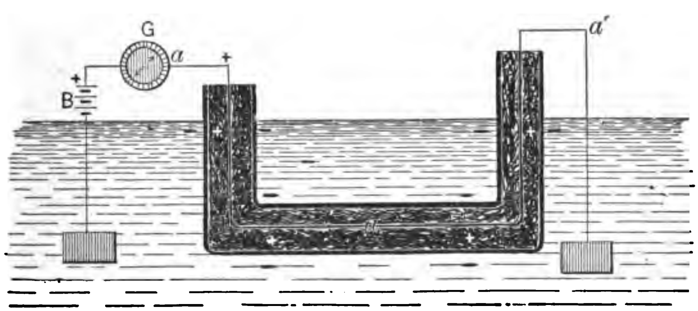


Fig. 99.

If we connect one end of a submarine cable to the positive pole of a battery, of which the other pole is connected

to earth, while the other end of the cable, *a'*, is insulated, the charge of electricity communicated to the first end will be quickly conducted to the other end, so that the whole length of the conductor will be charged with plus electricity, which will, of course, be of the same potential as the pole from which the charge proceeds. Now, surrounding the conductor is a non-conducting substance, and in contact with this is the conducting material of the earth or sea, to which is connected, as has been said, the negative pole of the battery. In other words, we have a long conductor charged with positive electricity and separated by a dielectric from another conductor. The charge will evidently induce negative electricity upon those parts of the earth or sea adjacent to the coating, so that we shall have all the conditions of a Leyden jar. The two opposite charges strive to recombine, but are prevented by the non-conducting nature of the coating. If now we break the connection with the battery, and at the same time give a path to earth at that place, the two charges can now combine; so that if we place a galvanometer in this path to earth it will indicate the passage of a current from the conductor of positive potential to the conductor of negative potential. Had we made the earth connection at the other end a galvanometer placed in that connection would have similarly shown a current from the insulated conductor to the earth. Had we made earth connections at both ends (after removing the battery) the current would have flowed through both, showing that it went from the middle of the conductor towards both ends.

As no conductor, however, is so perfect that it does not resist to some extent the passage of electricity, it takes time both to charge and to discharge the cable. If we have only one end connected to earth, the time required to discharge will, it is clear, be greater than if we have both ends so connected. Suppose we send a charge into a

cable whose farther end is connected to earth, by depressing a key, and then break the circuit by raising the key. A current will traverse the line, inducing a negative charge in the conducting material adjoining the insulating coating, and will finally reach the end, pass to the earth, and then the discharge of the line will follow. If now a second charge be communicated to the cable before the first charge has been discharged, the effects of the two charges will interfere at the farther end, because the current due to the discharge of the first charge will prolong the first signal so long that it will become merged in the current due to the charge of the second. Thus we see that the rapidity with which signals can be made to succeed each other is reduced by the time required to charge and discharge. Evidently the greater the charge communicated to the cable, and the greater the resistance of the conductor, the longer the times required for charge and discharge, and therefore the greater the retardation. So we see that, in order to signal rapidly, it is best to use as small currents as possible, to have as good a conductor as possible, and to have the capacity of the cable as small as possible.

To carry out the first provision it is necessary in submarine telegraphy to use an exceedingly delicate receiving apparatus, as such a one can be used with much feebler currents than the ordinary electro-magnet and armature. The mirror galvanometer of Sir William Thomson, already described, is so sensitive that it will indicate the minute current generated by placing in salt water a steel and a brass pin, which are connected to the instrument, and it is therefore well suited for submarine telegraphy.

To carry out the other two conditions little can be done with submarine and subterranean cables without making them too expensive. The core is always made of copper, which is the best conductor of electricity next to

silver; but as copper is very expensive, economical reasons prevent increasing the size of the conductor beyond a certain point. As every good insulator, too, has considerable inductive capacity, and as there are practical limits to the thickness of the insulating coating, every submarine cable of any length must possess considerable capacity, and therefore present a limit to the rapidity with which signals can be transmitted through it.

Retardation on Land Lines.—The phenomenon of retardation affects also the rapidity of signalling upon land or aerial lines, though in a lower degree. In a land line we are able to satisfy the third condition necessary to rapid signalling—that the conductor shall have small capacity. Here the insulator, or dielectric, between the two conductors, the line and the earth, is the air. As this dielectric has a small specific inductive capacity, and as the distance between the earth and the line is so great that it is very thick, its inductive effect is slight. This explains why we can telegraph so much faster over land lines than over submarine and underground lines; and why it is so difficult to telephone over the latter, unless they are quite short.

In order to carry out the second condition favorable to rapid signalling (that the wire should be as good a conductor as possible), the Postal Telegraph Co. have adopted a compound wire, which consists of a steel core, which gives the necessary strength, and a coating of copper, which gives the necessary conductivity. The practical results secured with this wire on a line between New York and Chicago have fully justified the expectations which theory raised.

In order to facilitate the discharge of a line it is common to connect the sending end to earth just as the circuit is broken, or to send into the wire a weaker current in the opposite direction to neutralize the charge in the first half of the cable. Defective insulation sometimes ac-

complishes the same result, provided that the leakage is not so great as to materially reduce the strength of the current.

Automatic Telegraphy.—In order to produce the succession of currents more rapidly than can be done by hand, systems of automatic telegraphy have been devised in which this is accomplished by mechanical means. In nearly all of the systems (and there are many) the message is first prepared for transmission upon a long strip of paper. The usual manner of preparing the message is to perforate a piece of paper tape with a series of slots and round holes which correspond to the dashes and dots representing the words to be telegraphed; sometimes a series of small holes being used instead of a slot. In order to do this it is usual to employ a perforating-machine, which is somewhat similar to a type-writer, except that pressing the keys causes perforations corresponding to letters to be punched out of the paper, instead of causing the direct printing of the letters. When a sufficient number of messages have been thus prepared, the long, perforated paper tape is drawn between a metal roller connected to one pole of the battery and needles connected to the other pole, which make contact through the perforations and close the circuit. In the Wheatstone system, however, the contact is not directly made in this way, but is effected by needles which press upon the tape and, when perforations pass, operate light levers which act as pole-changers.

To receive the successive currents of varying length transmitted by either system, which follow each other too rapidly to be distinguished by the ear, registers are used. In the Wheatstone system a stylus operated by a polarized relay is employed, which responds to alternating currents in the manner already described; and in some other systems the registering is accomplished by chemical means. In this case the paper is moistened with some

chemical solution (iodide of potassium to which starch has been added, for instance), and passes over a metallic surface connected to one end of the line and under a stylus connected to the other end. As this solution conducts electricity, each little current from the transmitting apparatus passes through the paper tape. But in so doing it electrolyzes the chemical solution and makes a stain in the manner already described. This action is so rapid and so delicate that a very swift succession of quite feeble currents will leave traces upon the tape, so that it will be covered with the same succession of dashes and dots as was the tape at the sending end. These can be read off, translated into ordinary language, and sent to the person addressed.

In practice the extreme delicacy of the solution gives some trouble, as feeble currents induced from neighboring lines, or occasioned by leaks in the transmitter, sometimes occasion false indications. The paper, being moist, is also difficult to handle, and promotes a tendency of the stains to run together.

The Leggo System.—A comparatively new system, and one requiring no perforation, is that invented by W. A. Leggo, in which the message is prepared upon a cylinder of conducting material, which rotates upon a longitudinal axis on which is traced the thread of a screw, so that the rotating motion produces also a longitudinal motion. A capillary tube containing insulating ink is lightly pressed upon the cylinder by a spring, so that, when the cylinder is revolved, a spiral line is traced around the cylinder as long as the tube continues to press upon it. The tube is, however, fixed to a pivoted lever, which is prolonged beyond the pivot into a piece of soft iron which rests over an electro-magnet as an armature. Now, when a message comes in to the central station to be transmitted to a distant point, the cylinder is given a slow revolution. At each attraction of the armature the inking-

tube is lifted from the cylinder, while during the breaks the inking-point traces a line on its surface. When the message has been received, therefore, the cylinder has upon it a spiral line, in which there are breaks which correspond to the dots and dashes signalled. When a sufficient number of messages have been received to fill the cylinder the inking-tube is removed and the cylinder revolved back to its first position. A platinum point connected with the line is now made to press upon the spiral, and the cylinder is connected to the battery. The cylinder is then made to revolve, but very much faster than in receiving. While the platinum point rests upon the insulating ink no current passes; but whenever it comes to a break the circuit is closed. A succession of currents, therefore, corresponding to the dots and dashes received, traverses the line, and is recorded on chemically-prepared paper in the manner indicated above.

Autographic Telegraphy.—Many systems have been devised for transmitting telegraphically the fac-simile of a written despatch, of a signatúre, or even of a picture. The principle upon which most of the systems are based will be readily understood when it is pointed out that the method of automatic telegraphy just described is really one form of autographic telegraphy, because the receiving paper has imprinted upon it a fac-simile of the dots and dashes on the transmitting cylinder. To extend the use of this to the transmission of more complicated designs, it is only necessary to wrap the sensitized paper at the receiving end upon a cylinder similar to the transmitting cylinder, and to use clockwork and a synchronizing device, so that both cylinders will rotate at the same speed. If we now sketch or write upon the transmitting cylinder with insulating ink, and proceed as in telegraphing, whenever the stylus at the sending end comes into contact with the cylinder a mark will appear upon the receiving cylinder, which will be interrupted when the stylus strikes the

insulating ink. The design will appear upon the receiving cylinder, therefore, in white lines upon a colored background. To accomplish this in such a way that the design, as received, shall be in lines continuous, or nearly so, it is clear that we must revolve both cylinders upon axes with very fine screws.

In order to receive the design in dark lines upon a white ground many devices have been invented. One method of accomplishing this with the system just described will doubtless occur to the reader. Suppose the currents as they arrive pass through a relay which closes a local circuit whenever a current is *not passing*. If now our receiving cylinder be placed in this local circuit, it is clear that a mark will be made on the paper whenever the stylus at the sending end comes into contact with the insulating ink. Another method is to have the cylinder and sending stylus in short circuit with the battery, so that no current goes to line except when this short circuit is broken by the sending stylus coming into contact with the insulating ink.

CHAPTER XII.

THE TELEPHONE.

IT was while experimenting upon harmonic telegraphy that Alexander Graham Bell and Elisha Gray discovered the principle by which human speech may be electrically transmitted, and invented an instrument for applying that principle. To this instrument was given the name "telephone."

Reiss's Musical Telephone.—Before Bell produced an apparatus capable of transmitting speech, however, an intermediate step was taken by Philip Reiss, of Germany. It will be remembered that to transmit messages on the harmonic system a number of reeds are used, each one capable of transmitting a note of one pitch, but no other notes; so that to transmit a tune on this system it would be necessary to employ as many reeds as there are notes in the tune to be transmitted. Philip Reiss accomplished the transmission of tunes by his "musical telephone"—a simple device, in which a great number of reeds were replaced by a membrane fixed at all points of its circumference. A membrane so fixed possesses the property of vibrating to all tones. Reiss's musical telephone is represented in Fig. 100, in which A is a hollow box, M a mouth-piece communicating with the interior, and S a circular membrane covering a hole in the top of the box. Upon this membrane is glued a small piece of platinum, which is connected to one pole of a battery. Resting lightly upon this piece of platinum is a contact-point protruding downwards from one of the arms of a little tri-

pod which is connected with the other pole of the battery. The current runs through the piece of platinum, the arm of the tripod, along the line-wire, and around the soft-iron rod which lies upon the sounding-box, R. When a person sings into the mouth-piece the membrane vibrates at each note, vibrating rapidly to notes of high pitch, and more slowly to notes of lower pitch. At each vibration the contact-arm jumps up and down, thus breaking the circuit and closing it again. Consequently it breaks the circuit very frequently during the utterance of a high note, and less frequently during the utterance of a lower one. The successive currents traverse the coils of

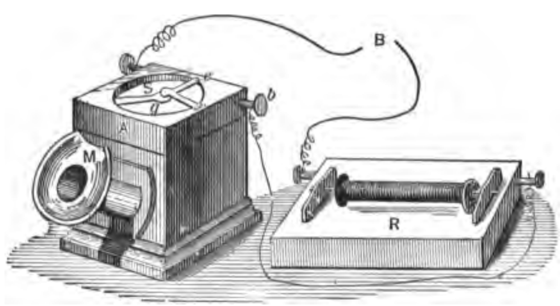


Fig. 100.

the electro-magnet on the sounding-box, and so subject it to frequent magnetizations and demagnetizations. Now, it is a well-known fact that a bar of iron, on being magnetized, becomes slightly elongated, and that it returns to its original length on being demagnetized. The rapid magnetizations and demagnetizations, then, produced in Reiss's electro-magnet subject it to longitudinal vibrations, which vary in rapidity with the notes sung. But these longitudinal vibrations cause the iron bar to emit sounds; and as the vibrations equal in number the vibrations of the note sung, the bar emits the same note. In this way Reiss was able to transmit tunes, but there is

nothing authentic to prove that he ever succeeded in transmitting speech. The sounds emitted were very feeble, and the invention was never made of any practical use.

Bell's Theories.—When Bell turned his attention to the invention of an instrument for transmitting speech, it was evident to his mind that some apparatus had to be devised more sensitive than any yet known. Understanding that each tone of the human voice is much more complex than that of a musical note, and that it possesses other qualities than pitch alone, he studied to produce an electric current which should vary as infinitely as the

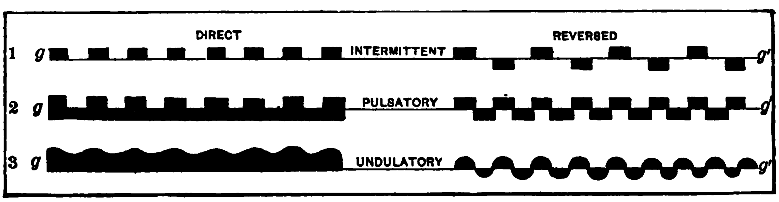


Fig. 101.

voice. He saw that no current which was made up of a succession of makes and breaks could ever do more than transmit pitch alone. In Reiss's instrument (the most perfect up to that time) the current was suddenly made, and at each break of contact was as suddenly broken, remaining during the interval at a nearly uniform strength. Now, as the voice, in uttering even the vowels, is composed of a mixture of tones, some of which it emits with greater force than others, and as the voice gradually rises and gradually falls, and is not composed of a succession of noises which abruptly begin and abruptly end, Bell saw the necessity of producing a current which should gradually rise and gradually fall in correspondence with the undulating vibrations produced by speech. Characterizing the currents in Reiss's apparatus as "intermittent,"

and currents in which an intermittent current was superposed upon a uniform current as "pulsatory," he concluded that, to accomplish his purpose, a current must be "undulatory." A graphical representation of the three kinds of current is shown in Fig. 101, in which the line gg' represents a zero, or no current, while the height above the line at any point indicates the strength of a positive current, and the distance below the zero line the strength of a negative current.

In the first column the undulatory current is represented as gradually rising above and returning to a uniform current upon which it is superposed, and in the second column as gradually changing from a positive to a negative current.

In order to produce an undulatory current Bell conceived of two methods, one by inducing a current of gradually varying electro-motive force, the other by varying gradually the resistance of the circuit.

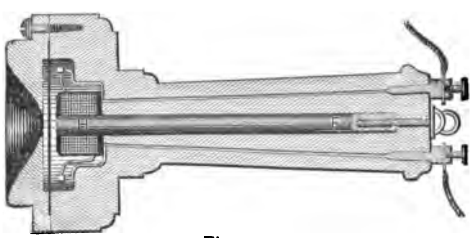


Fig. 102.

Bell's Telephone. — Passing over his first crude instrument, it will be sufficient to describe the form his telephone finally assumed (Fig. 102). It will be noticed that it operates by inducing a current of varying electromotive force.

F is a steel magnet surrounded at one pole by the coil, H, which is connected to the two binding-screws shown. To one is secured a wire which leads to earth, while to the other is attached the line-wire leading to the receiving telephone. This wire is connected to one of two similar binding-posts on the receiving telephone, whose other post is connected to the earth. The receiving telephone,

or, as it is usually called, the "receiver," is precisely similar to the transmitting telephone, usually called the "transmitter."

When a person speaks against the iron disc, D (Fig. 103), which is set very close to the coil, H, the disc is thrown into vibration, as in Reiss's telephone, the number of vibrations at each instant corresponding to the tone uttered at that instant. But the diaphragm is influenced not only by the pitch of a tone, it is influenced by its intensity also; for it will move to a greater distance from its normal position when actuated by a powerful sound than when actuated by a weak one, just as a swing will

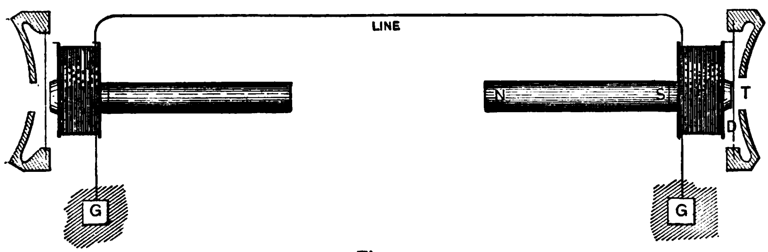


Fig. 103.

move to a greater distance from the vertical when actuated by a powerful thrust than when actuated by a weak one. Now, as all the sounds of a voice depend upon the pitch, the loudness, and the timbre (or peculiar property of any voice by which we distinguish it from any other voice), the diaphragm will vibrate in a different way for each sound.

It will be remembered that Faraday discovered that if a magnet-pole be moved near a closed circuit in such a way as to alter the number of lines of force it embraces, a current will be induced in that circuit whose direction and strength will depend upon the direction and the extent and velocity of the motion of the magnet.

It is evident that in Bell's telephone the iron disc,

being close to the pole of the steel magnet, becomes itself a magnet by induction. Therefore when this magnet, D, vibrates back and forth in front of the coil of fine wire, H, it alternately increases and decreases the number of lines of force embraced by it, and therefore induces in it alternating currents at each vibration. A series of alternating currents are then sent through the line to the receiver, which correspond in frequency to the vibrations of the diaphragm, and in strength to their amplitude, which in turn correspond to the pitch, loudness, and timbre of the voice.

When these alternating currents reach the receiver they pass through the coils, and therefore exert a magnetic force upon the iron disc in front of it, which is held in a permanent state of attraction by the steel magnet. When the current in the coils is in such a direction as to assist the attraction of the steel magnet, the disc is drawn nearer; and when it is in the opposite direction, and so opposes this attraction, the disc moves farther away. The succession of alternating currents, then, produces vibrations in the receiving disc precisely similar to those of the transmitting disc, so that the sounds emitted by the receiving disc are similar to those of the voice actuating the transmitter. From this it will be seen that the transmitter acts as a magneto-electric generator, converting the mechanical energy of the vibrations of the diaphragm into electrical energy, while the receiver acts as an electro-motor, converting the electrical energy of the currents into the mechanical energy of vibration. The voice itself, then, it will be noticed, is not transmitted from one point to the other.

Edison's Transmitter.—This instrument generates undulating currents by increasing and decreasing the resistance of a circuit operated by a battery. Mr. Edison discovered, in the course of a careful series of experiments, that carbon when subjected to pressure possesses a dif-

ferent resistance from that possessed when the pressure is absent, and that the variations in resistance of properly-prepared carbon are proportional to the amount of pressure. Using the apparatus shown in Fig. 104, he found that the deflections of the galvanometer, G, showed a much stronger current when a heavy pressure was placed upon C than when a light pressure was applied, showing that pressure decreases the resistance of carbon properly prepared.

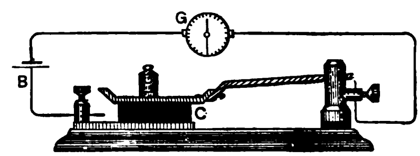


Fig. 104.

In adapting this principle to the telephone he constructed the transmitter shown in Fig. 105.

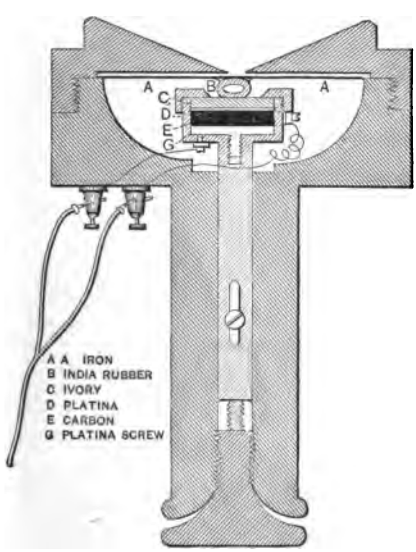


Fig. 105.

In this transmitter the carbon, E, is placed between two plates of platinum, which are connected to the two binding-posts as shown. The diaphragm, A, rests against a piece of rubber tubing, B, which in turn rests against a piece of ivory in contact with one of the plates of platinum. When the diaphragm is thrown into vibration it causes a varying degree of pressure to be exerted upon the carbon, and therefore causes a variation in the resistance of the circuit.

In later forms of transmitter Mr. Edison has abandoned the thin vibrating disc originally used in favor of a

rigid piece of metal. It was found that even when the piece of rubber tubing was used to check or "dampen" the vibrations of the diaphragm the articulation was somewhat muffled. The rigid plate vibrates throughout its mass, however, and thus causes a varying pressure upon the carbon (Figs. 106 and 107). In this form the carbon, C, lies between the metal of the frame and a sheet of platinum foil, P, which are connected each to one wire of the circuit, as shown.

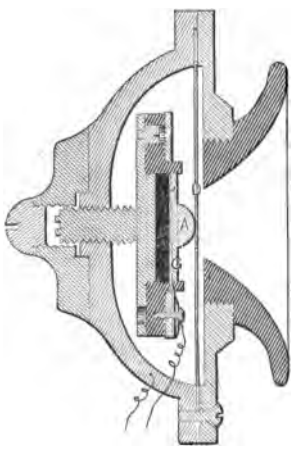


Fig. 106.

The best form in which to use carbon for this purpose has been found to be lamp-black from the lighter hydro-carbons, which has been deposited at as low a temperature as possible.

Edison's Motograph Receiver.—A most peculiar and original (though unpractical) form of receiver is that invented by Mr. Edison, in which no magnet is used, but in which the action is based upon the fact, discovered by himself, that when a piece of paper moistened with certain chemicals has an electric current passed through it the action of the current renders the surface of the paper almost frictionless, and that this effect ceases immediately as soon as the current ceases.

Fig 107.

In the receiver embodying this principle, and represented by Fig. 108, the brass shaft, *s*, which can be revolved by turning the little crank, K, has secured upon it a moist cylinder of chalk, C. Upon this presses a brass strip, T, tipped with palladium, which is rigidly secured to the

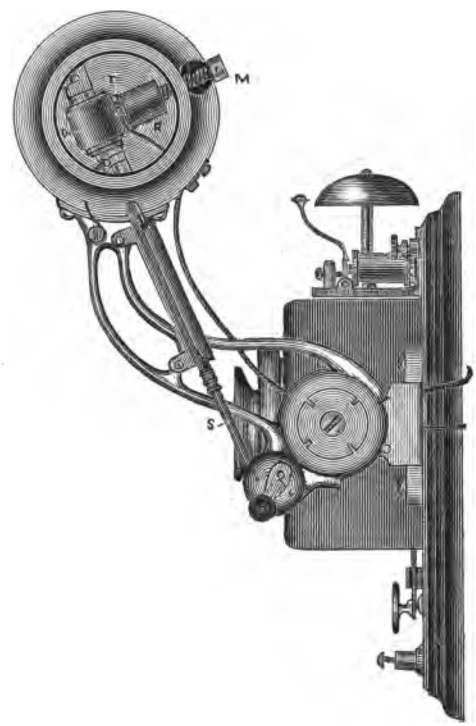


Fig. 108.

diaphragm lying in the plane of the paper. The brass strip, T, is pressed against the chalk cylinder by the rubber cylinder, R, the degree of pressure being regulated by the set-screw, M. The connections are as shown in the figure.

When ready to receive, the cylinder is made to re-

volve by turning the crank, K, in such a direction that the friction of the cylinder will pull the brass strip, T, away from the diaphragm, thus drawing the diaphragm in this direction. This will continue as long as no current is passing; but as soon as a current does pass the friction between the palladium and the surface will cease, and the diaphragm will instantly revert to its normal position, from which it will be instantly drawn again as soon as the current ceases. In this way the diaphragm is made to vibrate in accord with the diaphragm of the transmitter.

Induction Transmitters.—In using transmitters in which the resistance of the circuit is varied by varying the resistance within the instrument, it is clear that the current will be varied to a considerable extent when the ratio of the variation in resistance to the resistance of the whole circuit is great. It is also clear that this can be the case only when the resistance of the line is small; for if we have a long line with high resistance, the proportional amount by which this resistance will be varied by the necessarily slight alterations in the resistance of the transmitter will be too small to exercise any appreciable influence upon the strength of the current. To enable these instruments to be used successfully on long lines it is customary in practice to get over the difficulty by having the circuit of the battery and transmitter very short, terminating, in fact, in the primary wire of an induction-coil of which the secondary wire is in the main circuit. The varying currents sent through the primary wire when the transmitter is used induce alternating currents in the secondary coil. These currents have a sufficiently high electro-motive force to overcome the resistance of a long circuit, the degree of electro-motive force depending, of course, upon the amount of variation in the primary currents and the length of the wire in the secondary coil.

The Microphone.—The action of this instrument is very similar in some respects to that of Edison's transmitter, and many modifications of it are used in telephony. In its simplest form the microphone consists merely of two conductors in loose contact, forming part of an electric circuit, the current passing across the point of contact from one conductor to the other. Carbon is found to be the best material from which to make these conductors, though very good results can be obtained by using some other materials, notably platinum.

In Fig. 109 the little pencil of carbon shown is held loosely between two supports of the same material, and all are included in the circuit of the battery and the receiver. When the contacts of the carbon pencil are disturbed in any way a loud, grating sound is heard in the receiver. If a watch be placed upon the little platform shown, which is rigidly secured to the frame holding the supports, its ticking will so shake the frame as to affect the pressures upon the contacts; and, if the apparatus be delicately mounted, the light footfalls of an insect will do the same. This disturbing of the contacts has the effect of altering the degree of pressure between the carbon pencil and its supports, and, therefore, the resistance offered to the current. The current passing into the receiver is consequently of an undulatory nature and acts upon it in the manner already described, so that the dia-

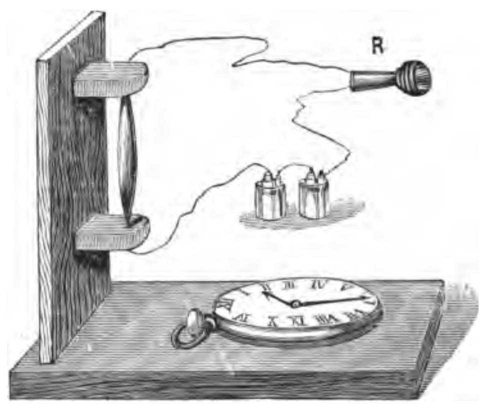


Fig. 109.

phragm is thrown into vibrations. If the pencil rests lightly in its supports the vibrations produced by a minute sound will affect the resistance about the contact-points to a much greater proportionate extent than if the pencil is firmly held. In the former case the ticking of a watch will sound to a listener at the receiver like the blows of a hammer; while if a pin be scratched along the surface the effect will be that of a discordant shriek. In adapting the microphone to telephony innumerable combinations have been made. It has not been possible to obtain its full amplifying effect in transmitting speech, however, for the reason that, if the contacts are made delicate, any loud sound will cause them to separate, thus breaking the current. To telephone low sounds, whispers, etc., however, the carbons may be adjusted with great delicacy.

Induced Effects.—It will be evident to any one who notes the extremely minute forces which produce telephonic effects that the currents used must also be extremely minute. In the magneto-transmitter of Bell the cause is the tiny vibrations of a diaphragm, and in the microphonic, or battery, transmitter the cause is the slight variations in the resistance of the transmitter; while even when an induction-coil is used, though currents of high electro-motive force are produced, yet these are obtained at the expense of such great resistance that the currents sent to line are extremely feeble. Now, it is evident that when wires pass in proximity to other wires carrying either telegraphic currents or the much greater ones used in electric lighting, there will be currents induced in the former by those in the latter. When the former, however, carry large currents themselves and operate instruments which are not very sensitive, the disturbing influence of the induced currents may not be appreciable; but when they carry tiny, telephonic currents and operate extremely sensitive receivers the induced currents may be, and some-

times are, so great as to overpower them or to inextricably confuse the sounds in the receiver. In order to overcome this induction effect the simplest way is to use a return wire running parallel to the other, instead of employing the earth as the return conductor. Any current induced will then, it is clear, be in one direction in one wire, and in the opposite direction in the other wire, so that the two currents will neutralize each other. The great cost of such a system precludes its use, however, in most instances.

Theories of Microphonic Action.—The action of the microphone is, in reality, but little understood, and is the cause of much discussion and controversy among scientific electricians. While all agree that its action is due to the disturbance of the contacts, many disagree as to whether the electric disturbance produced thereby is due to a minute electric light formed between the contacts, to variations in the heat at the contacts and therefore to changes in the resistance, or to mere alterations in pressure. Many experiments have been made to clear up the mystery, some of the most satisfactory being those in which the contact-points are brought within the field of a microscope; but as yet no exact conclusions have been reached.

Limit to Telephonic Transmission.—For practical purposes the use of the telephone, except over short distances, has been greatly restricted; and, though conversation has been carried on between neighboring cities, the results have not, as a rule, been very satisfactory. The great trouble is doubtless due to the minuteness of the currents used. In the case of the induction currents ordinarily employed with microphonic transmitters, their high tension, though necessary, has the disadvantage that it leads them to take every opportunity to escape afforded by damp air, defective insulation, etc.; and to this is, of course, added the effect of induction from neighboring

wires and from the wandering electrical currents which traverse the earth. Another very important cause is "retardation," which we found to affect telegraphic transmission also. In telephony the currents succeed each other with so much greater rapidity than in telegraphy that the troublesome effects of retardation become much more marked. It will be remembered that, to diminish the effects of retardation, the Postal Telegraph Co. have tried a compound wire of high conductivity with excellent results. A series of experiments with telephones of the ordinary kind over the same wire resulted also in the most satisfactory manner, showing practically the value of good conductors when rapidly recurring currents are used, whether in telegraphic or telephonic transmission.

Submarine and Underground Telephone Lines.—It will now be seen why it is more difficult to telephone through submarine and underground lines than through aerial lines. In the former case we have to rapidly charge and discharge condensers of large capacity, of which the dielectric is a substance of high inductive capacity, which separates the conductor by but a small distance from another conductor, the earth; while in the latter case the condenser is of very small capacity, the dielectric—the air—being of small inductive capacity and separating the conductor by a great distance from the earth. It is for this reason, besides others, that telephone companies do not desire to lay their wires underground. The expense would, of course, be considerable, and, as their wires would lie close to telegraph and electric-light wires, the induction effects would be great. Various devices are now being tried, however, which aim at reducing induction disturbance to a minimum.

CHAPTER XIII.

THE ELECTRIC LIGHT.

Arc Lights.—If we place together the points of two sticks of carbon, one of which is connected to one pole of a generator, while the other is connected to the other, the current will pass between them and the circuit will

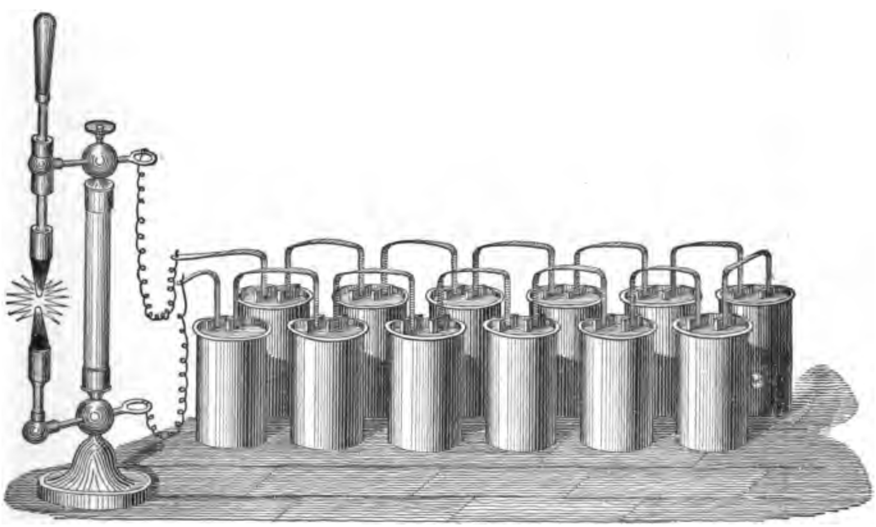


Fig. 110.

be complete. If now we draw these two sticks apart a slight distance we shall find that we have produced the most brilliant and powerful artificial light known (Fig. 110). At the instant of separation, and before the distance of separation has become more than a very minute quan-

tity, the extra current on breaking acquires an electro-motive force sufficient to enable it to jump across the intervening space. In so doing it detaches minute fragments from the positive carbon, which are at once volatilized by the heat engendered by the resistance. The carbon vapor thus formed being a conductor of electricity, the current has now a path from one carbon to the other. The resistance opposed by this path is, however, sufficiently great to generate enough heat to raise the vapor and the tips of the carbons to a white heat, so that they emit a brilliant light (Fig. 111). The solid matter of which the carbons are composed being, however, a better radiator than the vapor, the light due to their incandescence is greater than that due to the incandescence of the vapor. The current, in jumping across from one carbon to the other, keeps tearing away small particles from the positive carbon, carrying them over to the negative carbon and depositing them there. From this cause the carbons assume the shape shown in Fig. 111, a little crater being formed also in the under part of the positive car-

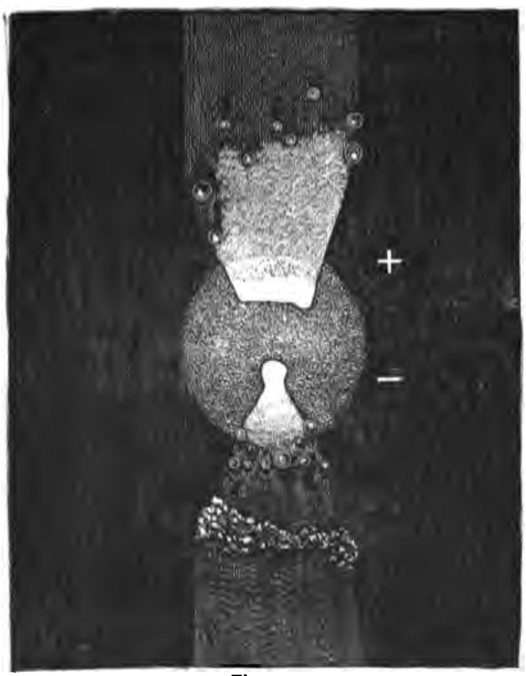


Fig. 111.

bon; the incandescence of the positive carbon being greater than that of the negative, and by reason of this crater, the light given out at an angle of forty-five degrees below the horizontal is greater than that given out in a horizontal plane or in one above the horizontal, the carbon being supposed to lie in a vertical plane with the positive carbon uppermost, which is found to be the most effective arrangement.

The heat of the "voltaic arc" (as it is called) formed between the two carbons is more intense than that of any other artificial source known. It will melt the diamond and vaporize platinum and gold. When burning in the open air both carbons waste away, the positive about twice as fast as the negative. In order, then, to produce a continuous light it is essential to devise some apparatus whereby the tips of the carbons will be advanced towards each other as fast as they waste away. In order to accomplish this numberless devices have been invented. One of the simplest and most effective "arc lamps" is that here described. It is not described, however, because it is any simpler or more effective than numerous other lamps, but because it is a typical lamp, so that, if its action is understood, that of any other lamp will become readily apparent on inspection.

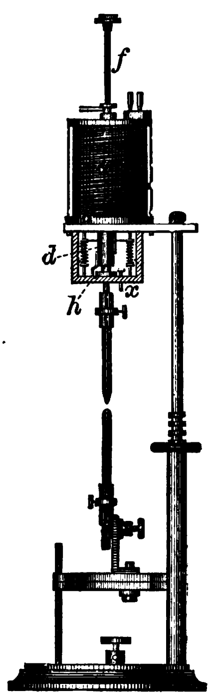


Fig. 112.

In the lamp represented in Fig. 112 the lower carbon is secured in a holder, while the upper carbon is actuated by the regulating mechanism. It is held in an "upper carbon-holder" (Fig. 113) attached to a brass "carbon-rod," *f*, which is steadied by the frame of the lamp.

Surrounding this carbon-rod is a ring, *h*, while directly below this ring is a lifting-finger. This finger is secured to a soft-iron core, *d*, which fits in the axial electro-magnet, or "helix," *a*. The coils of this electro-magnet are in the same circuit as the carbons, so that when the machine is started the current traverses the coils, passes through the carbons, and thence back to the machine. In passing around the electro-magnet the current energizes it, so that it attracts up within itself the soft-iron core, *d*. This core, in rising, carries up with it the finger, thereby causing it to tilt the ring, *h*, and bind it against the carbon-rod, *f*. The rise of the core, continuing, causes the ring, *h*, to raise the carbon-rod with it, thereby separating the carbons and producing the "voltaic arc." The distance to which the upper carbon is raised is limited by the head of the screw, *x*, which, it is clear, can be adjusted by turning the screw.

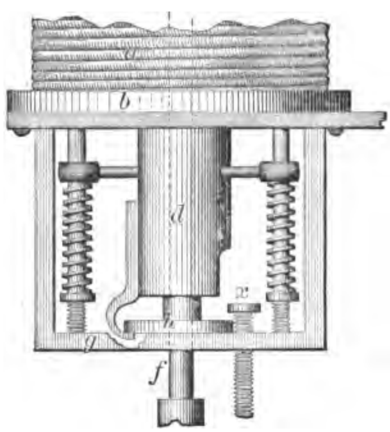


Fig. 113.

Regulation of the Arc.—But the gradual wasting of the carbons increases their distance of separation and the consequent resistance, and therefore diminishes the strength of the current and the power of the magnet. The magnet will soon become too weak to hold up the core, so that the latter will fall until it has decreased the resistance of the arc so much that the electro-magnet becomes strong enough to uphold it, when a new position of equilibrium is attained. After a while, however, the core will have descended so far in its efforts to keep the carbons at the proper distance apart that the ring, *h*, will

rest flat upon the frame. As soon as this occurs the carbon-rod will slide down through it, the resistance of the arc will be diminished and the current again increased, so that the core will be again drawn up within the magnet, thus raising to its proper position the upper carbon. With a well-constructed lamp the electro-magnetic action is so rapid and delicate that, if placed out of the influence of gusts of wind, the light will burn with surprising steadiness.

Arc Lamps in Series.—To use arc lamps upon an extended scale it is necessary to have a large number, and it is the most economical plan to place the lamps in "series," or one after the other upon the same wire.

When it was attempted to use in series lamps like that just described great difficulty was experienced. It was found that some of the lamps would burn well and that others would not burn at all. The cause of the trouble was explained by the following theory: As it was impracticable to make a large number of lamps exactly equal in all respects, some were necessarily more sensitive than others, so that when a number were put on the same circuit the electro-magnet of one lamp would allow its plunger to descend before the others would. This action would decrease the resistance, and therefore increase the current of the entire circuit, so that all the lamps would raise their upper carbons, even those which were on the point of lowering them. Whenever the resistance of the circuit became again increased the most sensitive lamp would again allow its carbon to descend, and thus readjust the resistance of the circuit. This action would keep on until the carbons of the sensitive lamp would be close together, at which time those of the other lamps would be far apart. It was seen to be essential, therefore, to make each lamp independent of the resistance of the circuit and of the action of the other lamps, and to have its regulating mechanism governed entirely by the resistance

of its own arc. To accomplish this the differential method invented by Heffner Von Alteneck was adopted. This method, it may be here remarked, is used in nearly every arc lamp in operation at the present day.

"Differential" Lamps.—In adapting it to the lamp in question a length of very fine wire was wound around the coarse coils of the electro-magnet, but in the opposite direction, and its ends were secured to the same binding-posts to which were secured the wires of the circuit. The fine-wire coil thus acted as a shunt, and the current divided between this shunt and the other circuit comprising the coarse coils and the carbons, according to the laws of branch circuits. The fine wire was so long and of such great resistance that only an extremely small fraction of the current went through it, and yet it was coiled into so many turns around the electro-magnet that the magnetic effect exerted upon the iron core was very great. This effect, it will be observed, was opposed to that of the coarse-wire coils. As the carbons wasted away, the increased resistance thus occasioned decreased the current in the coarse coils and increased that in the shunt coils. The resistances and the numbers of turns of both coils were then so adjusted with reference to the weight of the upper carbon-rod that the attractive force of the coarse coils was just balanced by the weight and the repelling force of the shunt coils when the carbons were at the proper degree of separation to produce the light desired. As soon as this limit was exceeded the upper carbon was fed down. The action of this apparatus, it will be noticed, depends entirely upon the resistance of the arc in the lamp in which it is placed, and is unaffected by the action of the other lamps.

"Automatic Cut-Outs."—In case any lamp on a circuit fails to feed from any cause the separation of the carbons will become greater and greater, until finally a flame dangerous to the lamp and its surroundings will

play about the carbons. The resistance of so great a separation also, if no means are taken to prevent it, will seriously impair the strength of the current and the brilliancy of the other lights. In order to prevent it every arc lamp used in cities is required to have an automatic cut-out, which will shut the current off from that lamp as soon as the resistance of the arc reaches a predetermined amount, but without affecting the supply of current to the other lamps.

To accomplish this with the lamp just described an electro-magnet, T, is used, which is wrapped with two coils wound in the same direction (Fig. 114). One coil is of fine wire in the shunt circuit; the other is of coarse wire, which terminates in the button, M″. When the resistance of the arc reaches the predetermined amount the electro-magnet, T, becomes sufficiently energized to attract the armature, A. This brings together the two buttons, M″ and M′, which closes a short circuit between the terminals, X and Y, by means of the coarse coils wrapped around T. A path is now given to the current, which can pass on to the other lamps, the faulty lamp becoming extinguished, and the buttons, M″ and M′, being strongly held together by the magnetizing force of the main circuit. If, however, the upper carbon should now feed, or be brought into contact with the lower carbon, the electro-magnet, T, will be short-circuited, the buttons, M″ and M′, will

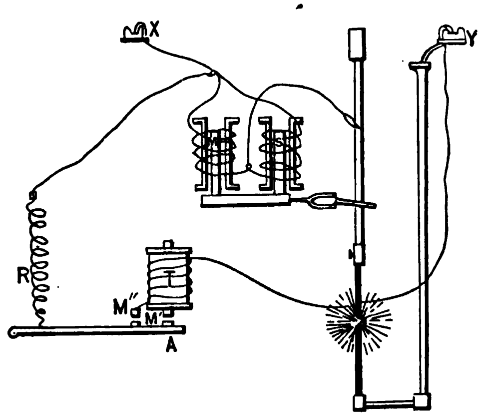


Fig. 114.

be separated, and the arc be re-established. Should the upper carbon fail to feed, however, the short circuit will be maintained and the current will pass on to the other lamps.

Clutch Lamps; Clockwork Lamps.—It will be noticed that in the lamp described the action depends upon a differential action on a *clutch* which grasps the upper carbon-rod of two electro-magnets, one in the main, the other in a shunt circuit. The majority of the series lamps in use fall under this general description. Lamps of this kind are said to work on the "clutch principle." There is, however, another large class which are said to work by "clockwork."

Clockwork Lamps.—In most of these the upper carbon-rod has a rack along its length, in which engage the teeth of a wheel which forms the first of a series of geared wheels. The upper carbon is raised by an electro-magnet in the main circuit attracting an armature, which is so arranged as to lock the last wheel of the gearing with a pawl, or detent, and at the same time raise the upper carbon-rod. It is clear that the weight of the carbon-rod tends to set in motion the train of gearing connected to it. To retain the rod in position, therefore, it is only necessary to keep a detent between the teeth of the last wheel. This detent is usually held in position by a spring, whose action is resisted by the attraction of an electro-magnet in a shunt. When the current through this shunt magnet becomes sufficiently strong (by reason of the increased resistance of the arc) the attraction of the magnet overcomes the force of the spring. The detent is therefore withdrawn, thus allowing the gearing to revolve and the carbon to descend until the amount of separation is so reduced that the shunt magnet has no longer power to keep the detent out of the teeth of the last wheel. The detent, being then forced in by the spring, locks the gearing and keeps the upper carbon stationary until the resistance of

the arc again becomes so great as to occasion the withdrawal of the detent. It is clear that very delicate action and a very gradual "feed" may be obtained by using a sufficient number of wheels.

Jablochkoff Candles.—These consist of two parallel sticks of carbon separated by an insulating substance (Fig. 115). In some electric candles made on the Jablochkoff principle this is simply air, but in those designed by the inventor it is some refractory material which fuses as the carbons waste, and increases the brilliancy of the light. Many materials have been used; that at last decided upon being a mixture of sulphate of lime and sulphate of barytes. The name given to the insulating material is "colombin."


Fig. 115.

The tips of the carbons are pointed, as shown in Fig. 115, and in order to allow the current to pass between them at the first a stick of conducting material is secured to both, as shown. As the positive carbon wastes much more rapidly than the negative one, it is necessary to use alternating currents with lights of this description; and from what has been said about charging and discharging lines it will be readily understood that the use of alternating currents upon a large scale is very uneconomical, involving considerable waste of energy. In any general system of electric distribution, moreover, motors are to be included as well as lamps; and alternating currents are not suitable for motors as at present constructed. To Jablochkoff must, however, be accorded the distinction of being the first to make electric lighting upon a large scale a practicable thing. Previous to his invention the voltaic arc was but a scientific toy and had no practical or commercial value.

Incandescence-arc Lamps.—In these lamps a small pencil of carbon connected with one pole of a generator is forced up into loose contact with a surface—often of carbon also—which is connected to the other pole (Fig. 116). The carbon pencil is so small that it opposes a great resistance to the current, and is therefore raised to incandescence. The contact between it and the opposing surface is so imperfect that a small voltaic arc plays between them, whose light is added to that emitted by the incandescent pencil.

Fig. 116.

In Fig. 116 the little pencil of carbon is represented as being held up against the lower surface of a carbon block by the weight.

The light given out by incandescence-arc lamps is exceedingly steady, and is not so harsh and brilliant as that of the voltaic arc. It is not so economical, however, and has never come into extensive practical use.

The Soleil Lamp.—A modification of this lamp is found in the Soleil, represented in Fig. 117. In this the two carbons, B and C, lie inclined in grooves whose ends are contracted, so that the carbons cannot descend below the position indicated. The block, A, is made from some refractory substance, like marble or compressed magnesia, and is recessed on its under side. A carbon strip joins the two ends of the carbons and permits the current to pass and establish the voltaic arc. When this is accomplished the lower surface of the mar-

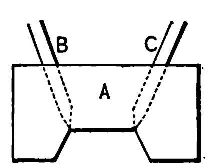


Fig. 117.

ble becomes intensely heated, and soon emits a beautiful light, whose color depends upon the nature of the material. With marble the color emitted is nearly white with a golden tinge, while with compressed magnesia the light is almost purely white. This lamp has been used considerably in Paris, and with excellent results as regards beauty and steadiness of illumination (Fig. 118).

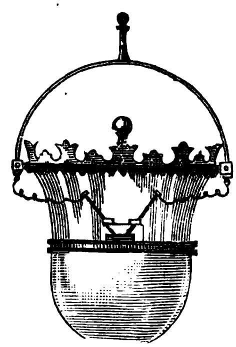


Fig. 118.

It is clear that, even if there be slight irregularities in the working of the machine or in the burning of the carbons, the incandescent marble will not immediately part with its heat, but will continue to radiate a steady light for even several seconds.

As regards economy, it has been found that these lamps consume more power than arc lamps giving the same amount of illumination. This is largely due, doubtless, to the loss in the conductors from alternating currents. The cost of the burning of the marble is also to be taken into account. Its simplicity and durability, however, and the steadiness of the light, are great elements in its favor.

Incandescence Lamps.—For giving a mild and gentle light, suitable for indoor illumination, lamps are made which consist simply of a curved filament of carbon, about the size of a coarse horsehair, sealed in a bulb of glass from which air has been exhausted. The resistance opposed by this filament to the passage of the current is so great as to develop an amount of heat sufficient to raise it to a white heat of great steadiness and purity.

Experiments were made without number during many years upon platinum wire. This material would, when a current was forced through it, emit a light which was

all that could be desired. It was not found to be sufficiently durable, however, and the scarcity and high cost of platinum precluded its use upon an extended scale.

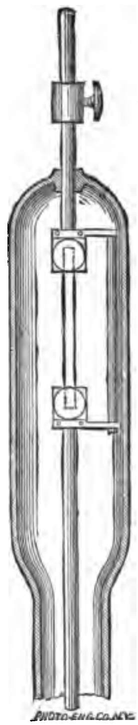


Fig. 119.

Starr's Lamp (Fig. 119).—The use of incandescent carbon in a vacuum was invented as early as 1845 by an American named Starr, who died two years afterwards, without ever securing the fruits of his invention, or even a patent. A patent upon it was, however, taken out in England, but in the name of one King, to whom Starr had imparted the knowledge of his invention. The records of Starr's experiments bear a strong resemblance to those of modern inventors who have followed in the path he pointed out.

Modern Lamps.—The incandescence lamps which have thus far come most extensively into practical use are those of Mr. Edison and Mr. Maxim, of New York, and Mr. Swan and Mr. Lane-Fox, of England (Figs. 120, 121, 122, 123). All of these gentlemen follow the same processes in general, but differ largely in the details of construction and manufacture. Bamboo fibre, cotton thread treated with sulphuric acid to render it structureless, parchment and grass fibre, are the materials most generally used. These are made into suitable shapes, and are subjected to intense heat. Mr. Maxim heats a paper filament to a high degree of incandescence in the presence of gasoline or other hydrocarbon, which becomes decomposed and deposits a hard, firm, and homogeneous layer of carbon upon the incandescent filament.

After a carbon filament has been formed it is attached to platinum wires which are to connect it to the circuit

(Fig. 120). These platinum wires are fused in a glass plug, B, in the base of a glass bulb, E, which is to form the

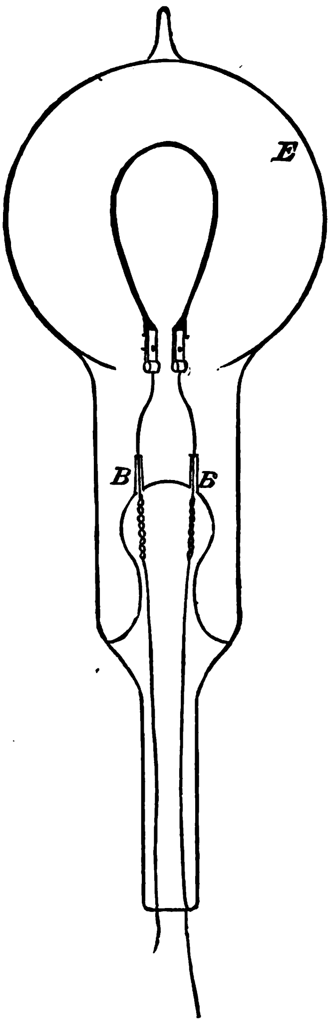


Fig. 120.

Fig. 121.

exterior of the lamp. The extremities of the filament are enlarged (Fig. 124), in order to facilitate its attachment to

the platinum wires. This is accomplished by Mr. Edison by clamping the two ends of the carbon upon the ends of the platinum wires and electroplating the junctions. In the lamp of Mr. Lane-Fox (Fig. 123) a quite different method is used of connecting the filament to the outside circuit. The ends, *c*, of the carbon filament are connected

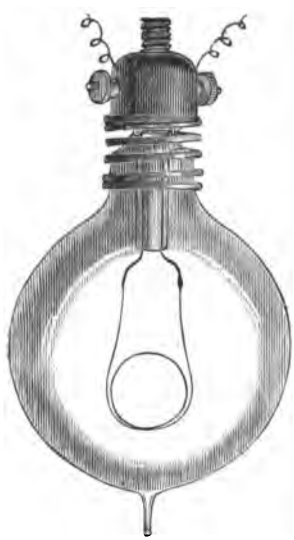


Fig. 122.

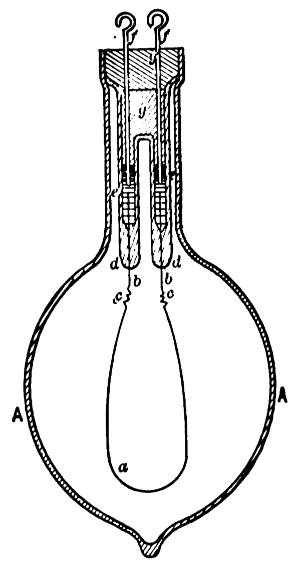


Fig. 123.

Fig. 124.

to fine platinum wires, *b*, which are fused in the solid bottoms of the glass tubes, *e*, containing mercury; and into these mercury vessels dip the terminals, *f*, to which are connected the wires of the outside circuit. After a carbon filament has been secured to the platinum wires the glass plug in which these platinum wires are fused is fused into the base of the lamp, the opening at the top of the lamp (Fig. 125) is attached to an air-pump

and the lamp is put in an electric circuit. The pump now begins to exhaust the air from the bulb, and at the same time a current is sent through the filament, raising it to incandescence. The circuit is then broken and the filament allowed to cool; afterwards it is raised to a higher incandescence than before, the exhausting process still continuing. The alternate heatings and coolings to which the carbon is now subjected not only test it severely as to its suitability for practical use, but they also serve to drive out any gases or vapors which may have become occluded in the pores of the carbon. When the exhaustion has become very perfect the neck of the bulb is sealed and removed from the air-pump. At the bottoms of the lamp the platinum wires of the Edison and Maxim systems so terminate with reference to the sockets upon which they are to rest that the simple act of placing the lamp upon its socket makes connection with the circuit automatically. In the former lamp the act of screwing the lamp into its socket brings the terminals of the lamp into the proper place; while with the latter the hooked terminals in the ends of the conductor within the socket are raised by the knobs shown, and hooked into the looped ends of the terminals of the lamp, the spring in the socket securing the lamp in position and necessitating a good contact.

Fig. 125.

CHAPTER XIV.

ELECTRIC MACHINES.

THE discovery that electric currents could be generated in conductors by moving magnets in their vicinity, or by moving them in the vicinity of magnets, attracted at once the attention of that class of men who are ever on the alert to adapt the forces of Nature to the practical requirements of civilized life, and inventors at once set to work to devise mechanical means for generating powerful currents by the relative motion of conductors and magnets. For many years they groped in the dark, their successes being the result of accident and experiment rather than of calculation. Now, however, that the magnetic nature of the current is known, and the relation between electro-motive force and magnetic lines of force is understood, the action of electric machines is an easily-comprehended matter, so that we can reason from cause to effect on theoretical grounds.

It will be remembered that we found a positive current to be induced in a circuit by decreasing the number of lines of force embraced by it, and a negative current to be induced by increasing them. It will also be remembered that we found that if a conductor be moved past a magnet-pole to the left of a person swimming in the conductor and looking along the positive direction of the lines of force, he will be swimming against the current induced by the motion; but that if the conductor be moved to his right he will be swimming with the current. In all the electric machines used at the present day we find simply different appliances for adapting these principles.

In many of the earlier forms of electric machines the movement was a reciprocating one, magnets being by this means alternately approached towards, and withdrawn from, conductors; in later machines, however, it has been found much less wasteful of energy to produce more gradual magnetizations and demagnetizations than were thus produced, and a rotary motion has been substituted. The forms assumed are almost innumerable, but they may all be divided, as shown by Prof. Silvanus Thompson, into three general classes.

In the first class, coils of wire are moved bodily through magnetic fields of different strength or in which the lines of force run in opposite directions. As the strength of a magnetic field may be considered as proportional to the number of its lines of force this action results in altering the number of lines of force embraced by each coil, and therefore in inducing in it electric currents (Figs. 126 and 127).

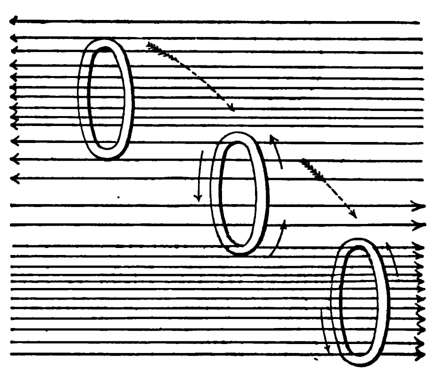


Fig. 126.

In the second class the coils are rotated between two dissimilar magnet-poles in a field of nearly uniform strength. In this way they are made to present different angles to the lines of force running from the north pole to the south, so that they embrace different numbers of lines of force (Fig. 128). It is clear that when a coil lies parallel to the lines of force no lines of force pass through it, but that when it lies perpendicular to the lines of force the number of lines of force passing through it is at a maximum.

In the third class a continuous cutting of lines of force is produced by rotating a conductor about the pole of a magnet (Fig. 129).

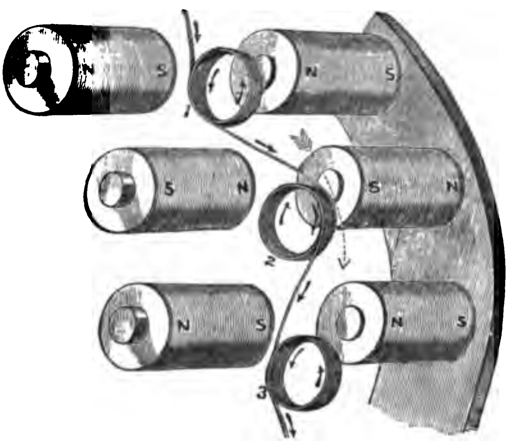


Fig. 127.

The machines first constructed, called "magneto-electric" machines, belonged to the first class. Fig. 130 represents an early type of such a machine, in which the two coils, A and B, were revolved about the axis, C, by turning the hand-crank, H. The alternate increase and decrease of the lines of force embraced by each coil induced in it currents whose direction changed twice during each revolution. The coils were connected together in the manner shown in Fig. 127, so that though the currents in the coils at any instant were in opposite directions, they still formed one continuous current through both coils.

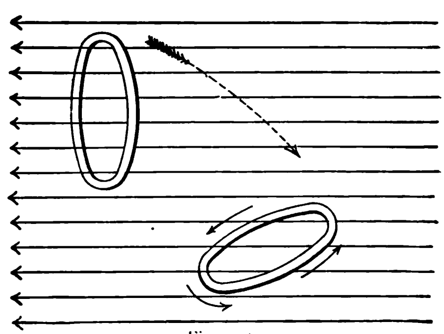


Fig. 128.

In order that the currents generated could be so combined as to produce a continuous current, a "collector," or, as it is sometimes called, a "commutator," was used.

The Commutator.—Fig. 131 shows a commutator in which two insulated metal strips, connected to the coils of the machine, are secured to an axle. Two brass or copper brushes, to which are connected the wires of the circuit, press upon the commutator. It is clear that as the coils and axle are revolved each brush presses in succession upon each metal strip, S and S. The brushes and commutator-strips are so arranged with relation to each other that just as the current in the coils is changed in direction each brush slips from one commutator-strip to the other, so that the current in the wire from one brush to the other must remain in the same direction.

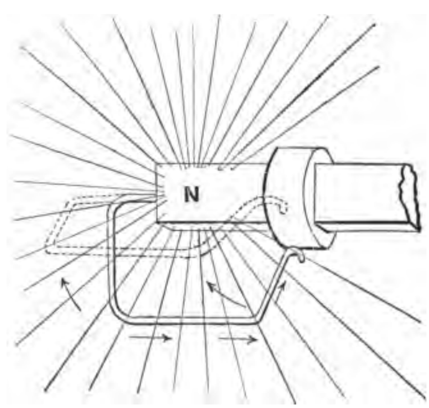


Fig. 129.

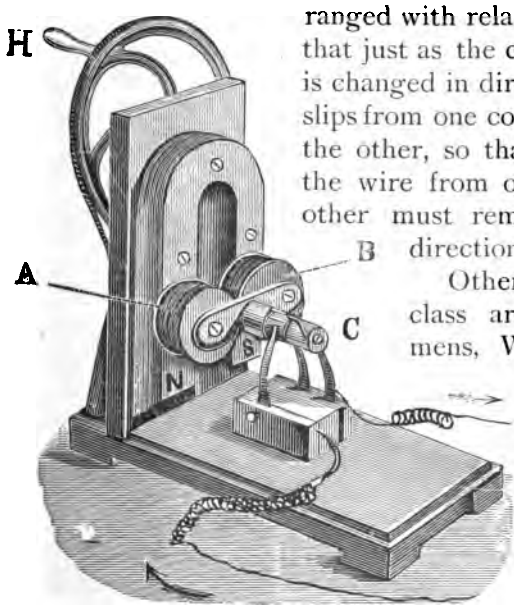


Fig. 130.

Other machines of this class are those of Siemens, Wallace and Farmer, Gordon, and Wilde, in all of which the same general principles are applied.

The Siemens Alternating-Current Machine.—As a modern type of

this class the Siemens alternate-current generator may be described. As will be seen from Fig. 132, the coils are carried around between the opposite poles of the stationary coils which project from the upright standards shown. These stationary coils are so arranged that alternate poles follow each other around the circuit and lie opposite each other. In most machines of this class the

Fig. 131.

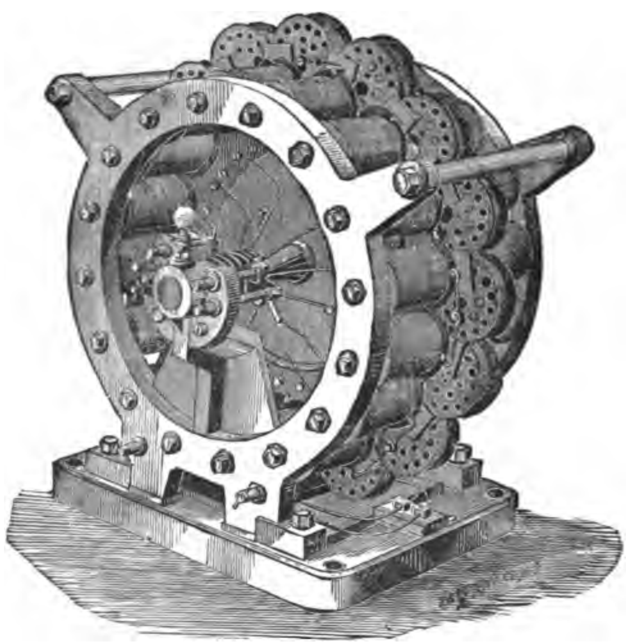


Fig. 132.

magnets are excited by currents furnished by a separate machine. As the successive coils are oppositely

placed as regards the poles of the magnets between which they lie, so that the currents are in opposite directions in adjacent coils, it is, of course, necessary to connect the coils in the manner shown in Fig. 127, in order that the currents may have a continuous circuit through all the coils.

Machines of the second class are by far the most numerous, efficient, and important. One of the earliest was that of Siemens, in which the coils were wound in a longitudinal groove in a long armature (Fig. 133), which is revolved between the two poles, A and B, of a powerful magnet (Fig. 134). In later forms of the Siemens continuous-current machine the coils are very numerous, and are wound so as to enclose the whole cylinder, in the manner shown in Fig. 135. The action of this machine may be conveniently studied by considering the effect on each wire as it passes the pole of each magnet. Remembering that if a conductor be moved past a magnet-pole to the right of a person swimming in the conductor and looking along the positive direction of the lines of force he will be swimming in the current induced by the motion, we see that if the armature be rotated in the direction of the hands of a clock (the pole A being a north pole) the current will be towards the back of the picture in the upper turns, and towards the front in the lower turns.

Fig. 133.

The ends of each coil are connected to two successive strips on the commutator which are insulated from each other, so that a continuous circuit is formed around the whole armature, each collector strip, forming a connection between each two adjacent coils. The advantage of

having a large number of coils lies in the fact that by this means a more uniform current is generated. If but two coils are used the current in each rises to a maximum and falls to zero during each revolution, so that the current generated partakes of the same undulating character. If we have a large number of coils, however, the current in some coil is at a maximum at the instant when that in another is at a minimum, so that greater uniformity of current is secured.

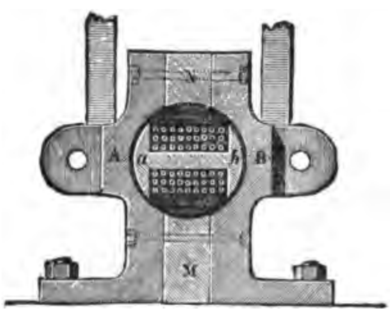


Fig. 134.

Edison's Machine.—As the conductors which lie lengthwise upon the drum are the only ones which do much service in cutting lines of force, it is advisable to reduce the resistance of the conductors that connect the wires upon one side of the armature to those on the other side. Mr. Edison accomplishes a very considerable reduction by using copper discs for this purpose. Edison's machine being intended to furnish a large current of not very high electro-motive force, it is not necessary to cut a very great number of lines of force per second, but it is necessary to have the resistance of the machine very small. It is not necessary, then, to revolve the armature at a very high rate of speed or to use very many turns on the armature. Mr. Edison replaces the wire coils of the armature by copper bars, which are connected to each other across the armature by discs at the ends of the armature, and each of the bars of the collector is connected to one of the discs at the adjacent end of the armature (Fig. 136). The core of the armature is made of thin discs of iron insulated from each other by sheets of tissue-paper, so as to prevent the passage through the core of what are called

"Foucault currents." These are currents which are induced in any mass of metal when it is revolved in the vicinity of magnet-poles. The induction of these currents not only occasions needless waste of energy, but the currents themselves heat the metal and therefore the

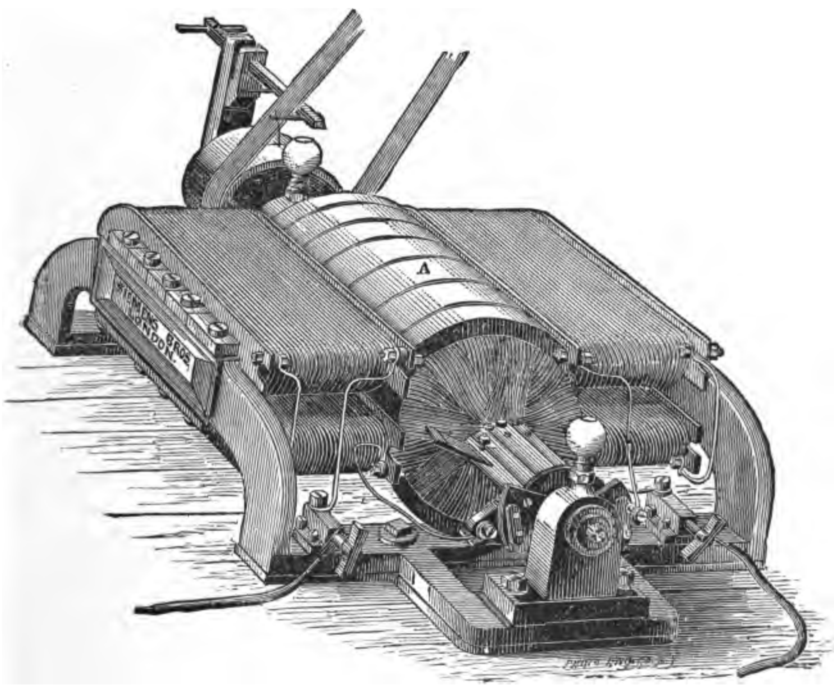


Fig. 135.

encircling wires, and so increase their resistance. In Mr. Edison's lighting systems the motive power for turning the dynamo is not transmitted by belting, as is ordinarily done, but the engine takes hold of the dynamo shaft direct (see frontispiece). The engine has a speed of about three hundred and forty-five revolutions per minute, which, with the type used, it has been found

thoroughly practicable to continue for several days and nights in succession. Quite recently an engine of one hundred and seventy-five horse-power, used for running one of Mr. Edison's dynamos in his station in New York, ran incessantly for sixteen days and sixteen hours without accident of any kind.

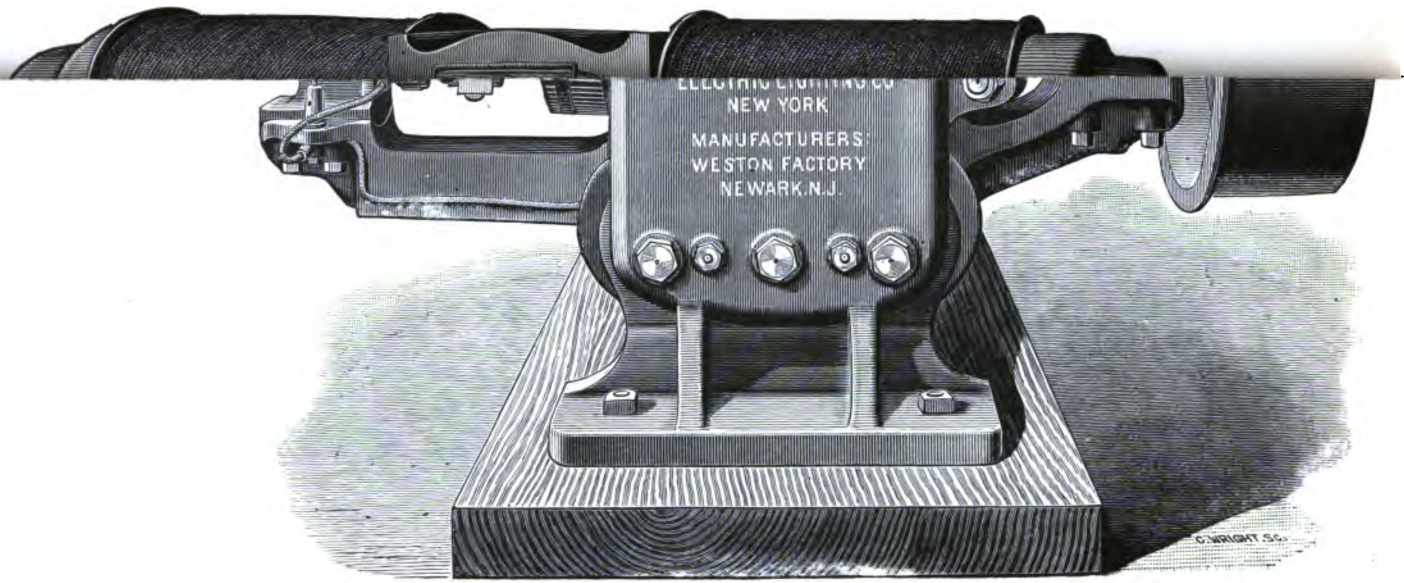
Fig. 136.

Weston's Machine.—One of the machines found most efficient in practice is that shown in Fig. 137. The armature-core is made of discs of iron placed one after another upon a spindle, and separated from each other by thin washers not so wide as the discs, so that there is an annular air-space between each two contiguous discs. After all the discs are on the armature presents the general appearance shown, and after the end pieces are put on coils of wire are wound in the longitudinal grooves and connected to the collector. The rotation of the armature forces air through the numerous air-spaces, so that the coils are kept cool, and the sectional form of the armature prevents "Foucault currents." As usually constructed the field-magnets are in shunt. It was the Weston machine which was selected for use as the motor in the electric railway at the recent Chicago Exposition, and it is the one used to supply the lamps on the Brooklyn Bridge.

Gramme's Machine.—Gramme's machine, a practical form of the invention of an Italian, Dr. Pacinotti, is represented in Fig. 138. In this machine the revolving coils are wound around a ring (Fig. 139) which can be revolved about an axis perpendicular to its plane. In rotating the coils successively approach and recede from

Fig. 137.—WESTON DYNAMO-ELECTRIC MACHINE.

Weston Sectional Armature-Core.



End View.

the magnet-pole, thereby presenting varying angles to the lines of force running from the north to the south magnet-pole (Fig. 128). Each coil is connected to two

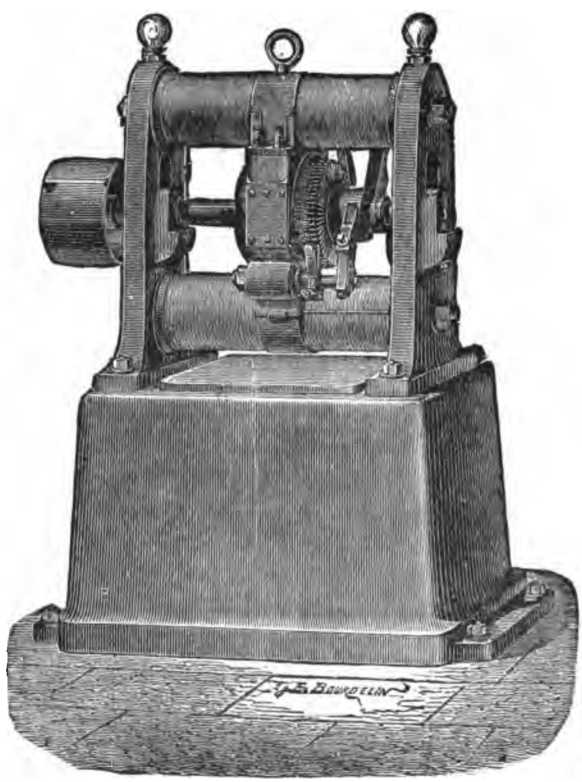


Fig. 138.

adjacent strips of the collector, and each strip acts as a connector for two adjacent coils, so that a continuous circuit is thus formed around the armature. The collector plays in this machine, and, in fact, in all electric machines designed for furnishing continuous currents, the

same part—*i.e.*, it collects the alternating currents generated in the armature, and delivers them as a continuous, uniform current to the brushes connected with the outside circuit.

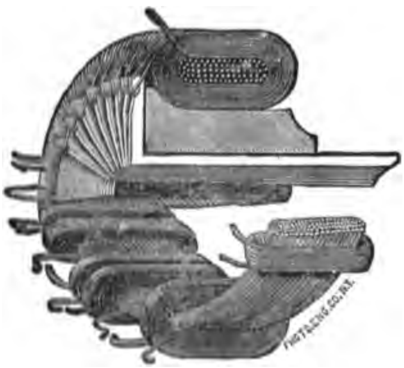


Fig 139.

Brush's Machine.—A very successful modification of the Gramme machine is that invented by Mr. Brush, of which a representation is given in Fig. 140. The great peculiarity of the Brush machine lies in the arrangement of the collectors and the coils, whereby each pair of the four pairs of coils is in turn cut out of the circuit during one-eighth of a revolution, so that there are only three pairs of coils in circuit at one time. The object in doing this is to get rid of the waste of energy necessitated by sending a current through one pair of coils during the time at which they are doing little good and cutting few lines of force. A little consideration will show that this is when the coils are very nearly at an angle of ninety degrees to the lines of force; for at this time the number of lines of force passing through these coils is at a maximum, but their *rate of change* at a minimum, because the rate of change varies as the cosine of the angle. The manner in which the useless pair of coils is cut out of the circuit is shown in Fig. 141. As will be seen, there are two sets of brushes and four commutators, one commutator for each pair of coils. Each brush is made to touch the commutators of two pairs of coils, which are not contiguous, but at right angles to each other. The two strips of each commutator are separated from each other by about one-eighth of the circumference; so that whenever these in-

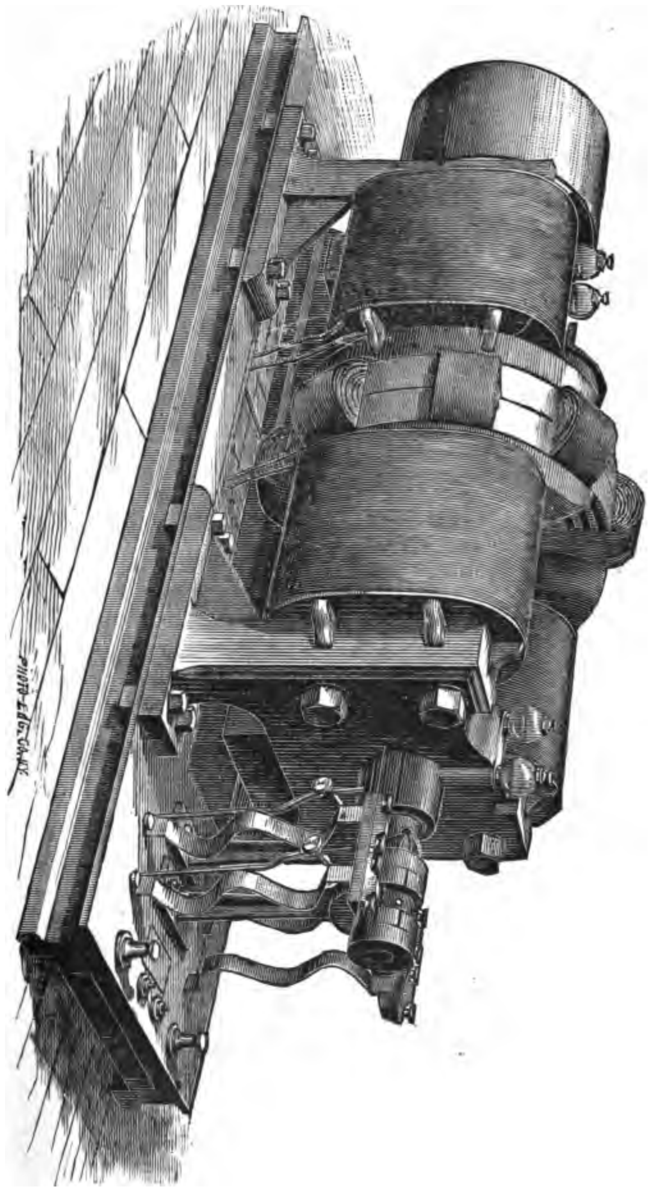


Fig. 140.

sulating spaces come under a brush the pair of coils corresponding to this commutator are cut out of the circuit. Now, the brushes are so placed that they come over

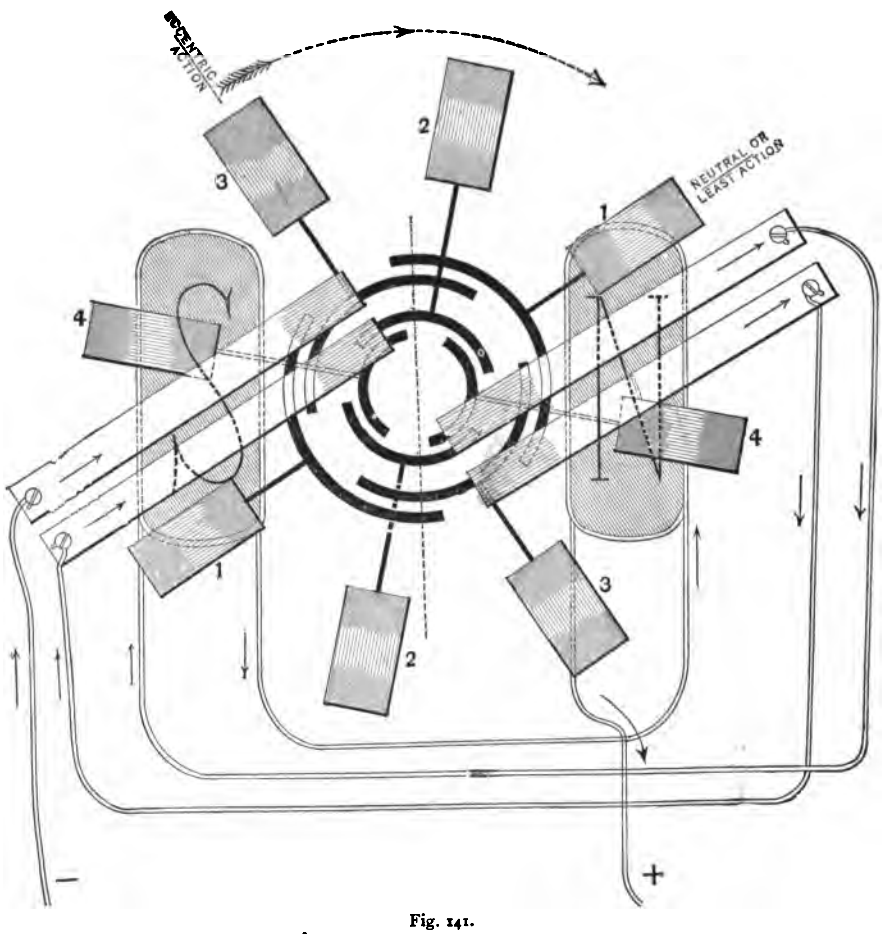


Fig. 141.

these insulating spaces just at the time when the coils corresponding are in the position of minimum action; and they come into contact with the strips of the commutator

again when they are approaching a position of greater effectiveness.

In this machine the four pairs of coils form four independent machines, the two coils of each machine being in series; but the four machines are joined in two pairs by the arrangement of the collector, the two machines thus formed being joined in series at the last, so as to generate one continuous current of high electro-motive force. Of the two machines thus joined in series, one has one pair of coils in the position of maximum effect, the other pair in the position of minimum effect, and therefore cut out. The other machine has both pairs of coils in circuit, and both in positions of medium effect. The current finally generated may, therefore, be said to be that of two machines joined in series; one machine having two coils in series in a position of maximum effect, the other machine being composed of two machines joined in parallel, each of these machines consisting of two coils joined in series and lying in positions of medium effect.

Though the theory and the connections of the Brush machine seem very complicated, yet the construction and operation are quite simple. The results secured in practice, moreover, are such as verify the theoretical advantages of cutting out the useless coils.

Machines of the Third Class.—Machines of the third class have been constructed and used, but never to any considerable practical extent. In most of these a conductor is made to rotate about one pole of a magnet in some such way as that represented in Fig. 129, so that it effects a continuous cutting of the lines of force sent out from the pole. Remembering the rule that if a conductor be moved to the right of a person swimming in the conductor and looking along the positive direction of the lines of force he will be swimming with the current induced by the motion, we can easily predict the direction in which a current will flow in a machine of this class.

Excitation of Magnets.—Remembering that the electro-motive force furnished by a machine (usually called a "dynamo machine," or simply "dynamo") is dependent upon the rate of cutting lines of force, and that this is dependent upon the velocity of rotation, the number of turns of wire in the armature, and the strength of the poles between which the armature is revolved, we see the importance that the method used for exciting the magnets assumes. There are five general systems for exciting the magnets of a machine (called the "field-magnets"), and machines are sometimes divided into five classes, according to the system used:

1. Those in which the field-magnets are permanent magnets of high steel. Machines of this kind are called "magneto-electric machines."

2. Those in which the field-magnets are of soft iron wrapped with wire coils traversed by a current from another source of electricity, such as a battery or another machine. These are called "separately-excited machines."

3. Those in which the field-magnets are made of soft iron wrapped with coils of wire traversed by a current generated by the machine itself—that is, the current, on leaving the brushes, passes around the field-magnets and excites them before passing to the external circuit. The action of this machine is due to the fact that, no matter how soft the iron of the field-magnets may be, after it has once been magnetized it retains a trace of residual magnetism. When the armature is set in rotation by a belt from an engine or by other means, this slight magnetism induces a miniature current in the coils of the armature, which current, going around the field-magnets, increases their magnetization a little. This increases the current in the coils of the armature, which in turn increases the magnetization of the field-magnets. The two forces keep reacting upon each other in this way until the field-magnets

have reached their point of saturation, or until they have reached the highest degree of saturation obtainable with the speed of rotation used. Such a machine is called a "series dynamo," the armature and magnets being in series.

4. Those in which the field-magnet coils are traversed by a current which is taken as a shunt from the brushes. In this machine the current from the armature, on reaching the brushes, splits into two parts, one part going out into the external circuit, the other part going around the field-magnets. The advantage of this mode of excitation lies in the automatic adjustability which it effects. In case the external resistance increases more current is shunted through the field-magnets, so that their magnetization, and therefore the electro-motive force of the machine, is increased. In case, on the other hand, the external resistance is diminished less current is shunted through the field-magnet coils, so that their magnetization, and therefore the electro-motive force of the machine, is decreased. It might appear at first sight as if this method of excitation would not be suitable for supplying incandescence lamps in multiple arc or parallel, for the reason that lighting more lamps calls for more current, and yet decreases the external resistance, because it gives more branches for the current to traverse. But by having a set of adjustable resistances in the shunt circuit, as Mr. Edison does, the magnetism of the coils may be increased or decreased at will by an attendant's cutting out or introducing resistances, so that the electro-motive force of the machine may be kept constant, no matter how many lamps are lit or extinguished. Dynamos of this kind are called "shunt-wound dynamos."

5. Those in which the field-magnets are excited by a combination of the two preceding methods—that is, both by coils in series with the armature and in shunt.

The early types of machines used permanent or steel

magnets as field-magnets; but for the reason that steel cannot be magnetized so strongly as soft iron, and for the reason that the electro-motive force of a machine depends, as has been shown, on the strength of the poles between which the armature revolves, it has been found more economical to substitute electro-magnets. A certain portion of the current is taken from the external circuit, in order to excite the field-magnets, but this loss, it is found in practice, is more than compensated by the increase in electro-motive force. Steel magnets are, moreover, more expensive than soft-iron ones. For very small machines, however, such as those turned by hand to ring the bells used as calls in telephone apparatus, steel magnets are found to be preferable, and are employed in practice.

From the fact that the iron in the armature becomes heated by the Foucault currents generated in it by being revolved between the poles of magnets, and by the reversals in magnetism produced by the alternating of the currents traversing it, it might seem better to substitute for iron some non-magnetic and non-conducting substance, like wood. The use of wood would certainly obviate the difficulty, but it would decrease the electro-motive force of the machine, because it would decrease the number of lines of force running from pole to pole of the field-magnets through the armature. Iron, it will be remembered, gathers up lines of force by offering to them a better pathway than air does; so that the iron of the armature core gives more lines of force to be cut by the revolving coils, and therefore increases the electro-motive force.

In some machines the armature is made hollow, in order to get a good draught of air through it, so as to cool the wires; and a stationary iron piece lies inside to concentrate the lines of force.

Characteristic Curves of Dynamos.—These useful curves, first suggested by Dr. Hopkinson, and since

used by Marcel Deprez and many other scientists, offer graphic representations of the characteristics of machines.

To lay off the "characteristic" of any dynamo at any speed, disconnect the field-magnet coils from the armature-coils, and excite them separately by an exterior source. Now set the armature revolving at the given speed, and measure the strength of the current sent through the field-magnet coils, and then the E. M. F. of the armature produced by revolving it between the field-magnets, magnetized by that strength of current. Now lay off the two lines Y and X (Fig. 142), meeting at O. Divide both by the same scale, and lay off on X the distance, O B, equal to

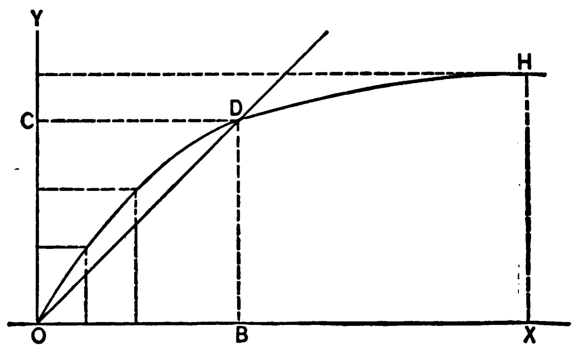


Fig. 142.

the strength of the magnetizing current in ampères, and then lay off on Y the distance, O C, equal to the resulting E. M. F. in volts. Erect the perpendiculars D B and D C. The point of intersection, D, will be one point of the characteristic.

Now increase the strength of the magnetizing current by regular degrees, measure the E. M. F. for each current, and erect perpendiculars as before. Join the different points of intersection, and the curve thus produced will be the characteristic curve *for that* velocity of rotation. It is obvious that the characteristic for the same machine

if worked at a different speed will be dissimilar, because the E. M. F. for any given strength of magnetizing current will be greater if the velocity of rotation is greater, and will be less if the velocity be less, because the E. M. F. depends upon the number of lines of force cut per second. But, having the curve for a given speed, the only thing necessary in order to get the curve for another speed will be to multiply the ordinate for each strength of current by the fraction $\frac{v'}{v}$, in which v is the velocity for which the curve is constructed, and v' the velocity for which the characteristic is desired (Fig. 143). Knowing

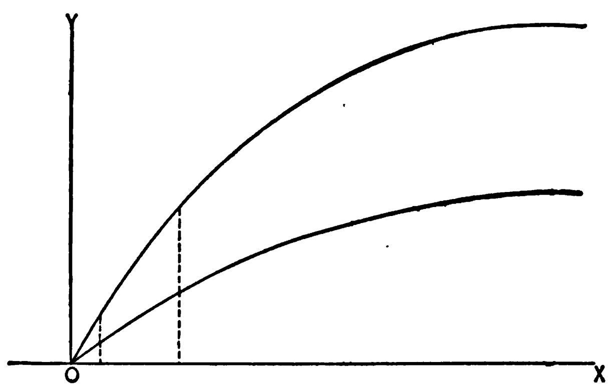


Fig. 143.

the characteristic for any machine, we can now connect the armature and field-magnet circuits. On now measuring the strength of current produced we have simply to take the ordinate of the curve, corresponding to the abscissa representing the strength. In other words, if Fig. 142 represents the characteristic of a machine for any velocity of rotation, and we find a strength of current in the magnets corresponding to O B, then the E. M. F. must be B D. And as $C = \frac{E}{R}$, $R = \frac{E}{C}$; so that the tangent of

the angle D O B must be the resistance, because this tangent $= \frac{E}{C}$.

It is clear that we can tell from the shape of the curve the relations of the current to the magnetization of the magnets. The curve at first rises rapidly, showing that for the weaker currents the E. M. F. increases rapidly, and therefore the magnetism in the magnets, but that after a while any increase in the magnetizing current has but little influence in increasing their magnetism; in other words, that the magnets are near their point of saturation, as shown by the very gradual rise of the curve after passing the point H, for instance.

In the curve represented in Fig. 144, let D O X = the total resistance $r + x$ of the circuit, in which r is the resistance of the machine and x that of the external circuit, and let E O X = the resistance, r.

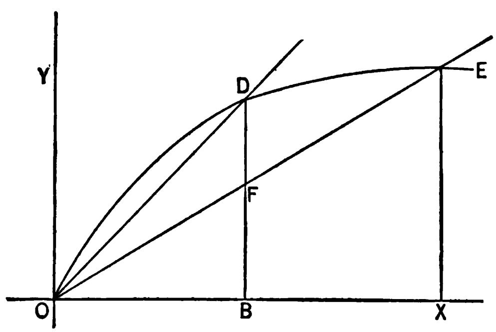


Fig. 144.

Then that portion of the total E.M.F., B D, utilized in overcoming the resistance of the machine must be F B, and that left for the external circuit the part D F. The greater D F, the greater the potential at the terminals of the machine. This shows us at once the necessity for making the internal resistance of the machine as small as possible.

CHAPTER XV.

ELECTRO-MOTORS.

An electro-motor may be said to be the converse of a dynamo, because an electro-motor is a device for converting electrical into mechanical energy, while a dynamo is a device for converting mechanical into electrical energy. A good illustration of the relations between dynamos and motors may be found in the Bell telephone, for the transmitter converts the mechanical energy of the vibrations of the diaphragm into electrical energy, and the receiver converts this electrical energy back into mechanical energy. The electro-motor used in practice, however, has a rotary motion, which is much more capable of being transmitted to machinery than a reciprocating one.

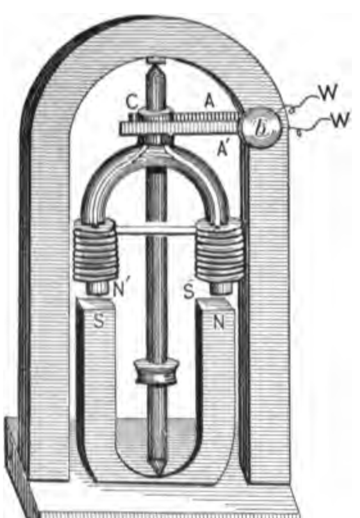


Fig. 145.

The analysis already made of the action of the dynamo will, if reversed, apply very nearly to that of the electro-motor. In fact, if a strong current be passed through a dynamo it will immediately become an electro-motor and take up a rotary motion.

A very simple form of electro-motor, though not a

very efficient or modern one, is that shown in Fig. 145. The current enters by the brushes, A and A′, passes to two strips on the collector, C, and then around the coils, N′ and S′. The north pole, N, of the permanent magnet attracts the south pole, S′, formed at one end of the iron yoke, and the south pole, S, of the permanent magnet attracts the north pole, N′, formed at the other end.

This yoke being capable of revolution about the central spindle, N′ and S′ are attracted to S and N respectively. Just at the instant, however, that they arrive opposite the attracting poles, the collector, C, in revolving brings under A the strip formerly under A′, and brings under A′ the strip formerly under A (Fig. 146), so that the brushes slip from one to the other, and thereby reverse the current in the coils and cause N′ and S′ to immediately interchange polarities. They are therefore instantly repelled from the poles formerly attracting them, but their momentum has by this time carried them by N and S, so that the direction of repulsion is the same as that of the former attraction. The rotation, continuing, brings them now under the influence of attracting poles, so that the action just considered is again repeated and a continuous rotating motion is established. This motor, it will be noticed, is very nearly the exact converse of the electric machine first considered, and it will be seen that in the motor, as in the generating machine, the external current is continuous, and the internal alternating.

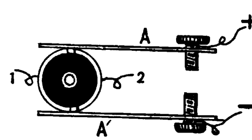


Fig. 146.

For the reason that steel cannot be given as high a degree of magnetization as soft iron, and that it costs more, motors are usually made in which the field-magnets are electro-magnets. It is evident that the magnet represented in the figure could be replaced by an electro-magnet simply by replacing the steel magnet with a similar shape

of soft iron, and wrapping one of the wires, W, around it between the binding-post, *b*, and the brush A′. The action in this case is, of course, the same as when the steel magnet is used.

Siemens's Machine makes an excellent motor. The action of the early form of machine, shown in Fig. 147, is very similar to that just described. The armature in this case is a long electro-magnet, of which *a* and *b* are the poles. The current traversing its coils forms, let us suppose, a south pole at *a* and a north pole at *b*, so that these poles are attracted by the north pole, A, and the south pole, B, of the field-magnets respectively.

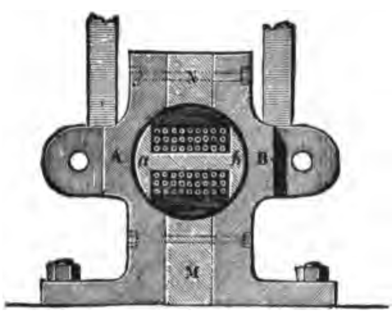


Fig. 147.

When *a* gets opposite A, and *b* gets opposite B, the current in the armature-coils is reversed by reason of the brushes interchanging collector strips; so that *a* now becomes a north pole and *b* a south pole, and both are repelled. But by reason of the momentum of the armature this repulsion is in the same direction as the attraction was; so that a continuous rotary motion is set up, just as in the case last considered. In both of these motors, where there are but two strips on the collector, a disadvantage will at once be noticed, arising from the fact that there are "dead-points." When S′ is directly opposite N, and N′ directly opposite S, the force between the two pair is in a line perpendicular to the axis, and has no tendency to produce rotation. The motor is then in exactly the same position that a single engine is when the piston is either at the end or the beginning of its stroke. The momentum of the moving parts in both cases carries them past the dead-point after momentum has once been

established · but undesirable interruptions may often occur in starting. To obviate this trouble in steam-engines two cranks are used, one ninety degrees in advance of the other upon the shaft; in electro-motors a number of turns are wound at angles to each other upon the armature, as in the modern types of Siemens and Gramme machines.

The action of the modern type of Siemens machine will be easily understood if we remember the analysis of its action as a generator. Each conductor of the armature when near a pole is deflected to the right or left, according to the principle already laid down in discussing the relative actions between a conductor and a magnet-pole. For it is clear that, if a fixed conductor traversed by a current will move a free magnet-pole, then if the conductor be free and the magnet-pole fixed the conductor will be deflected in the opposite direction. Now, in a Siemens machine used as a motor we find simply a number of conductors traversed by currents deflected in succession by magnet-poles. Remembering the direction in which lines of force run around a conductor—*i.e.*, in the same direction as the hands of a clock move, as seen by a person looking in the direction the current flows—we see the rationale of the following rule, which is the converse of Ampère's rule already given for predicting the direction of deflection of a magnet-pole: *Imagine a man swimming with the current in a conductor opposite either the north or the south pole of a magnet, and looking along the positive direction of the lines of force (that is, away from the north pole or towards the south pole); then the conductor will be deflected towards his left.* In case the conductor makes a turn between two dissimilar poles, as in the case of a Siemens electro-motor (see Fig. 148), then, as the line of sight is towards the south pole in both instances, the directive effects in both the upper and the lower turns will assist each other, and produce a rotation in the direction of the arrow.

The position of maximum effect is clearly that of the

two conductors lying between the two poles, and that of minimum effect is that held by two conductors whose plane lies perpendicular to the line joining the poles. In the former case the number of lines of force embraced by the circuit of the two conductors is at a minimum, but the rate of change is at a maximum; while the reverse

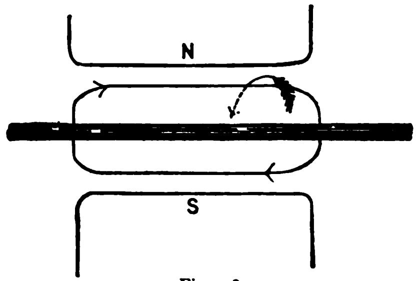


Fig. 148.

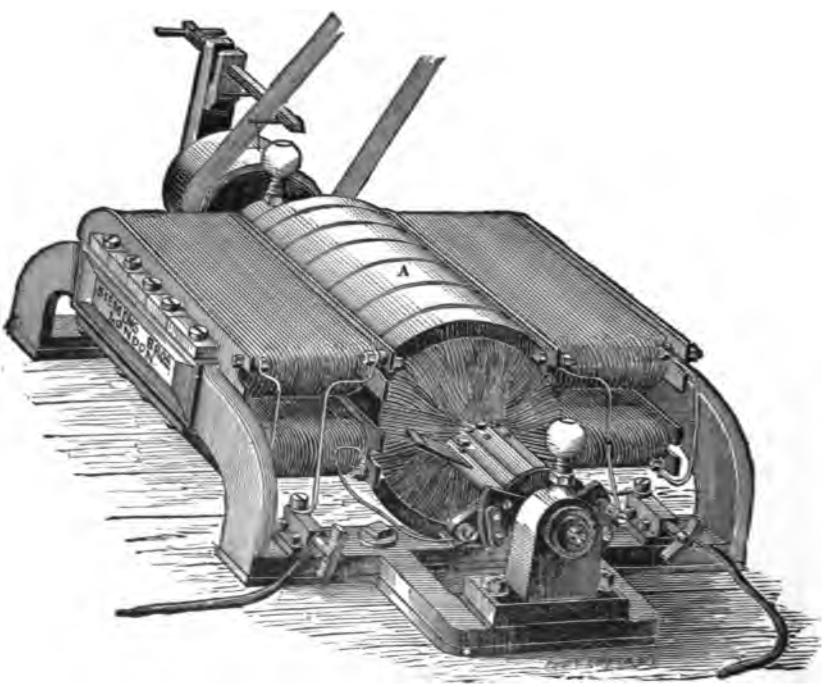


Fig. 149.

is the case with the circuit whose plane is perpendicular to the lines of force. Therefore the positions of maxi-

mum and minimum directive effect coincide with the positions of maximum and minimum generative effect.

Keeping in mind the convenient rule just given, we can at once predict the direction of rotation of a Siemens motor, if we know the direction of the current. In Fig. 149, which represents a Siemens series machine, in which A is a north pole, if the current in the upper turns of the armature is towards the front of the picture, the direction of rotation must be that of the hands of a clock, because this is towards the left of a person swimming with the current and looking in the positive direction of the lines of force—*i.e*, towards the south pole.

In the case of a Gramme machine used as a motor, or of any machine of the Gramme type, in which the armature consists of a series of turns of wire coiled on a ring, the action can be studied by the same process of considering the motor as a dynamo reversed. Observing the same rule as that observed in studying the action of a Siemens motor, and changing the diagram used in explaining it to that in Fig. 150, which represents two rings rotating about the axis, *x x*, it will be seen that the currents in the inside of each ring tend to produce rotation in a direction opposed to that set up by the currents in the outside turns. The outer turns are, however, in a more powerful field and farther from the axis of rotation, and therefore are

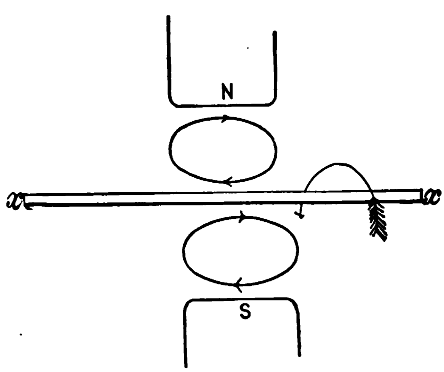


Fig. 150

enabled to produce rotation in a direction independent of that which the inner turns tend to produce. The inner turns, however, must exert a certain opposing force, and

this force weakens the strength and velocity of the resultant rotation. The effect of the inner turns is, however, reduced to a minimum by the fact that the armature-core around which they are wound is of iron.

It has already been shown that a magnetic substance offers an easier path to magnetic lines of force than the air offers, so that they will go through a magnetic substance rather than through air, if the chance is offered. If, therefore, we place between two poles, N and S, an iron ring (Fig. 151), the lines of force will rather pass through the substance of the ring than through the air-space inside, so that this inner space will be nearly destitute of lines of force. The ring acts, then, like a *screen*. Evidently this is precisely the case with a Gramme ring, so that the turns on the inside of the ring revolve in a field so weak that its effect is insignificant. The rotation of the ring of a Gramme motor is practically, therefore, dependent solely upon the direction of the currents in the outside turns.

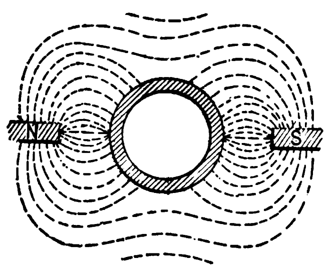


Fig. 151.

Direction of Rotation of Different Types.—The preceding remarks clearly apply to all electro-generating machines, whether their field-magnets be made of steel, be wound in series or shunt, or be separately excited. A slight consideration will show, however, that the direction of rotation is influenced by these conditions.

1. Magneto Machines.—Suppose in Fig. 152 that a current in the direction indicated to be generated by revolving the armature in the direction of the hands of a watch. If now we wish to use this machine as a motor, it is clear that we must send the current through in one direction or the other, according to the direction of rotation desired. For if we use a current in the same di-

rection as that generated, it will traverse the coils of the armature in the same direction, and, therefore, cause a reverse rotation.

2. Separately-excited Dynamos.—The same remarks clearly apply to a separately-excited dynamo, for

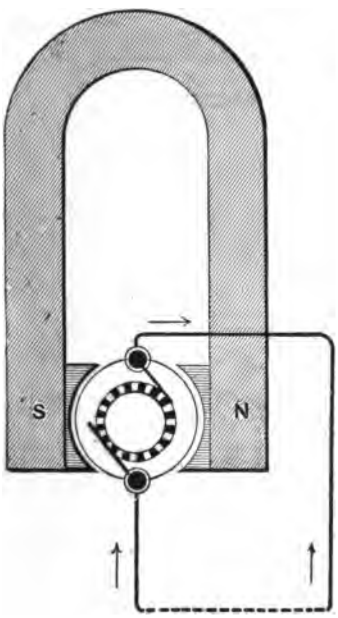


Fig. 152.

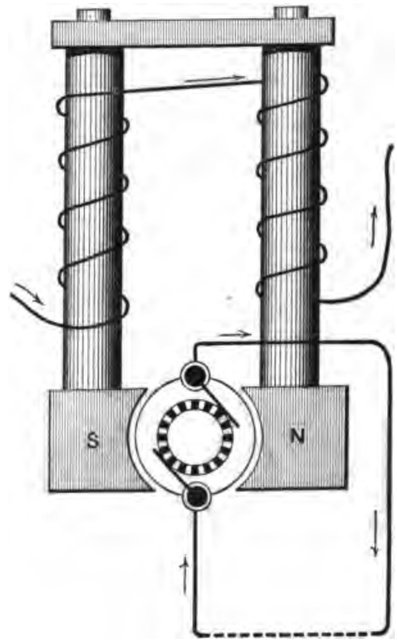


Fig. 153.

the polarity of the field-magnets is likewise independent of the direction of the current (Fig. 153).

3. Series Dynamo.—In this case we must make connections with the machinery we wish to operate by the motor, on the supposition that the armature will turn in the direction indicated by the arrow, no matter in what direction we send the current through. Suppose (Fig. 154) that the dynamo, in revolving in the direction of the hands of a watch, generated a current in the direction

shown, and that, desiring to use it as a motor, we sent through it a current in the same direction. The polarity of both magnet-poles and the direction of current in the armature-coils being the same, the rotation would clearly be reversed. Let the current now be reversed. The polarity of the magnet-poles becomes instantly reversed,

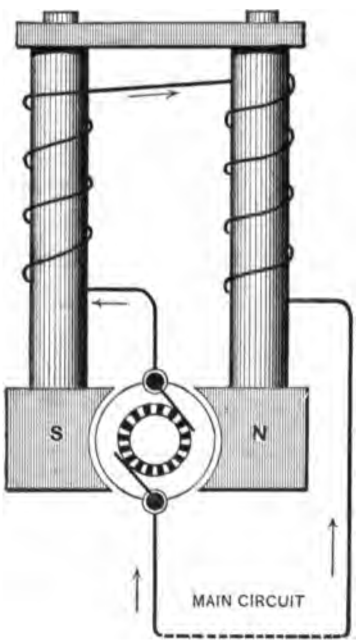


Fig. 154.

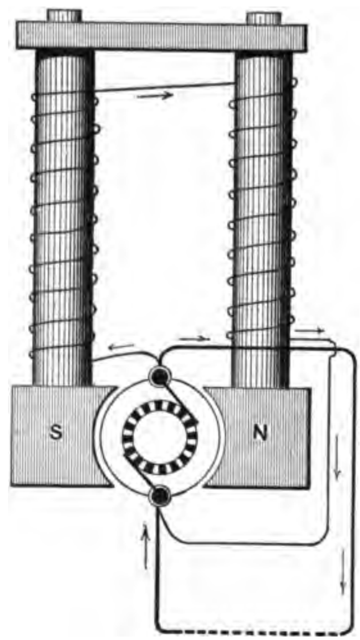


Fig. 155.

but at the same time the direction of the current in the armature-coils is also reversed, so that the direction of rotation as a motor is the same in either case.

4. Shunt Dynamo.—In this case a precisely contrary state of affairs is found. Suppose that the shunt dynamo shown in Fig. 155 generates a current in the direction indicated when the armature is revolved in the direction of the hands of a watch. Wishing to use the

machine as a motor, let a current in the same direction be sent through it. This current, on reaching the lower brush, divides, part going through the armature and part through the field-magnet coils. But the direction of the current now traversing the field-magnet coils is in the opposite direction to that generated, and the current in the armature-coils is in the same direction. Consequently the direction of rotation is unchanged. Let us now send a reverse current through. This divides at the upper brush, so that the currents both in the armature and the field-magnet coils are the reverse of those just considered; therefore the direction of rotation still remains unchanged.

Counter Electro-motive Force.—In all of these cases, however, no matter what the direction of the rotation, it is evident that this rotation must tend to produce a current due to the revolution of the conductors in a magnetic field, and that this current must oppose and weaken the actuating current. We have seen that for any given machine the electro-motive force depends upon the velocity of rotation; so that if a motor turns rapidly it must generate a greater counter electro-motive force than if it turns slowly. That this is advantageous will be clearly seen when it is considered that if a motor is doing work of any kind—in running a train or turning a circular saw, for instance—the effect of the work is to reduce the speed of the motor, and therefore call for more current from the generator, thus causing the consumption of more zinc if a battery is used, or more coal if a dynamo and engine are used; while, when the motor is doing no work, or very light work, it will spin rapidly around, thereby generating a high counter electro-motive force, which reduces the strength of the actuating current and the consumption of zinc or coal, so that the consumption of fuel is regulated by the demands of the circuit.

Regulating Electro-Motors.—Yet the fact that electro-motors revolve with greater rapidity when doing

no work than when under a load necessitates some device for regulating their velocity of rotation; for it is clear that the gravest inconvenience would result in using a lathe, or other tool, if it would spin around at high velocity as soon as the work was removed, for on bringing up another piece of work the shock might be so great as to injure the tool or perform other mischief. Therefore with electro-motors, as with all other kinds of machinery, we require some automatic device for keeping the speed constant.

In most of the devices which have been invented for producing this desirable result some arrangement is found by which the motor, on attaining a certain speed, automatically breaks the circuit, and does not establish it again until the speed of rotation has fallen to the predetermined point. This is frequently done by having governor-balls attached to the motor, the angle at which they stand out depending, of course, on the speed; so that when the speed has reached the prescribed limit, the balls, by virtue of the position which they then assume, force apart two points which were in contact, and across which the current was flowing.

It is evident, however, that such a method of regulation cannot be otherwise than spasmodic in its action. A more scientific and satisfactory solution of the difficulty would appear to be that of Professors Ayrton and Perry, in which the government of the motor depends upon the action of the current alone, and not upon any mechanical additions.

Ayrton and Perry's Governor.—The action of their governor is based upon the fact that the counter-current generated by a motor varies with the speed of revolution; and that in any dynamo or motor no current is generated until a certain speed, called the "critical" speed, is attained. The field-magnets of the motor are wound with extra coils of wire from the circuit in such a

direction that their effect is to demagnetize the field-magnets. These coils are so arranged, both in number and resistance, that when the motor reaches a predetermined speed (the critical speed) the counter-current causes such an increase of current in the reverse coils wrapped around the field-magnets that their magnetization, and therefore the speed of the motor, are materially lessened. Should the speed of the motor rise high above the critical speed, the inverse current, which increases very rapidly as soon as the critical speed is passed, will cause the inverse branch current in the coils to exert a very strong demagnetizing influence, so that the demagnetizing effect of these branch coils, or, in other words, the regulating power of the system, increases as the necessity for it increases. The demagnetizing coils are in series with the armature, while the magnetizing coils are in shunt to it (Fig. 155*a*). Therefore the energy of the counter-current set up by the motor, though it checks the speed of the motor, is not subtracted from the energy of the system, because this counter-current is in the same direction as the current sent through the armature. In other words, this governor acts like a sensitive cut-off in a steam-engine, which cuts off the steam automatically when the load is decreased, so that the horse-power expended is proportional to that required, instead of putting a heavy brake upon the fly-wheel, which might check the speed of the engine, but would not decrease the energy expended —merely replacing the load by the useless friction of the brake.

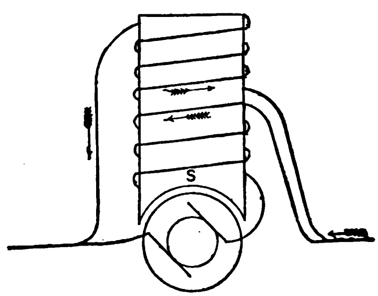


Fig. 155*a*.

Electric Hammer.—This is a device for accom-

plishing by means of electricity what is usually accomplished by steam. Fig. 156 represents an electric hammer

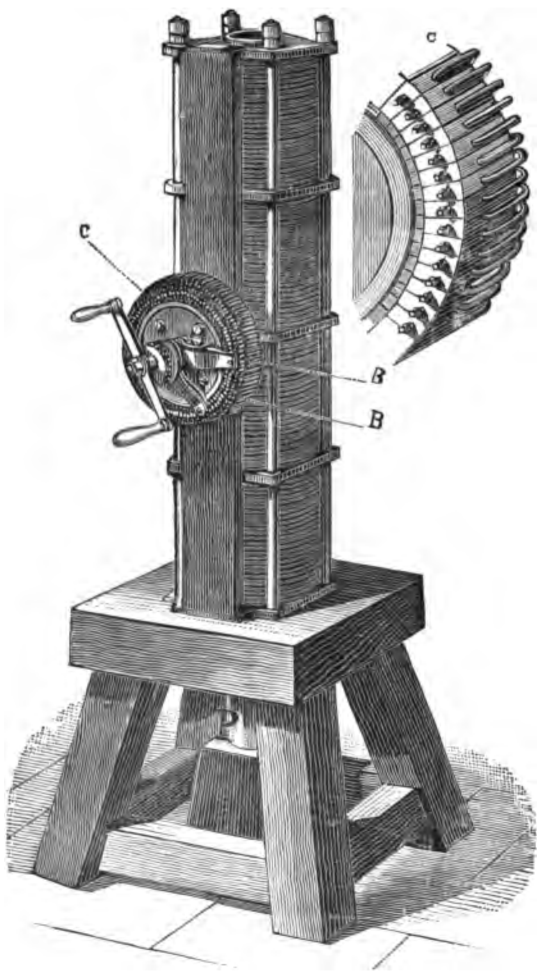


Fig. 156.

of Marcel Deprez, in which a succession of coils, placed one above the other and connected each to a circular

commutator, are adapted to suck up an iron plunger, P. The double handle shown is mechanically connected to the two brushes, B B, so that by turning it around the brushes make contact with the successive contact-strips of the commutator, C. The brushes are so electrically connected with the circuit that the current enters by one and departs by the other, traversing in so doing those coils whose contact-strips lie between the two brushes. If now the plunger lies at the bottom in the position shown, and the double handle is turned around in such manner as to make contact with the lower ten coils (or such other number as the angle of the brushes is adjusted for), the plunger will be sucked up by them; if the handle is now revolved still further, so as to send the current through higher coils, the plunger will be sucked up higher; and thus by turning the handle the plunger can be raised to its highest position. If the direction of movement of the brushes be then reversed, the direction of movement of the plunger will be reversed, so that a powerful blow may be given at the end of the stroke, the weight of the plunger being added to the driving force of the currents.

The angle of the brushes can be altered so as to include a greater or less number of coils in the circuit at one time, in order to proportion the resistance to the strength of the current, and both to the work to be done. Using a current of forty-five ampères, says *La Nature*, and adjusting the brushes to embrace fifteen sections, the effort developed on the plunger was one hundred and fifty-two pounds, the plunger weighing fifty-five pounds, and the whole solenoid being one metre in height.

By suitably manipulating the double handle the plunger may be raised and lowered with any desired rapidity, so that a blow may be given of great force or of great delicacy, as required.

CHAPTER XVI.

ELECTRIC DISTRIBUTION OF POWER.

IN order to distribute power by electrical means from where it can be generated in large quantities to places where it is wanted but cannot be readily generated or procured, it is necessary to devise means whereby the power can be economically converted into an electrical current, whereby this current can be economically transmitted along a conductor with minimum loss both from leakage and from heating the conductor, and whereby the current, on reaching its destination, can be economically reconverted into mechanical energy.

Electrical Work.—In order to express the relations between the amount of work transmitted and the amount received, or, in other words, the economy or efficiency of an electrical system, it is necessary to understand that electrical work, or the work performed by a current, can be expressed in the same units that mechanical work is expressed in.

Unit of Electrical Work.—It will be remembered that the unit of electrical work is the *erg*, and represents the work performed by a C. G. S. unit of electricity in falling through a C. G. S. unit difference of potential. Expressing the number of units in a current that have passed in a given time by Q, and the difference of potential through which they fell by E, the work done in ergs is clearly QE. Current is, however, expressed in terms of its strength; that is, the number of units that pass in one

second. Denoting this by C, and the difference of potential by E, the work done *in one second* is clearly CE ergs.

But, as was explained in speaking of practical units, the units of strength and quantity employed in practice are 10^{-1} C. G. S. units, and the unit of potential 10^{8} C. G. S. units. Therefore the work done by Q coulombs falling through E volts is

$$\frac{Q}{10} \times E \times 10^{8} = QE \times 10^{7} \text{ ergs};$$

and the work done *in one second* by a current C is

$$\frac{C}{10} \times E \times 10^{8} = CE \times 10^{7} \text{ ergs}.$$

The unit of electrical work practically used is that performed by one coulomb falling through one volt; and the unit of electrical power is the work done *in one second* by a current of one ampère falling through one volt. To the practical unit of work the name *joule* has been given, and to the practical unit of power the name *watt;* both being suggested by Dr. Siemens. The watt has been more extensively adopted than the joule, because it is so readily applicable to the measurement of horse-power. The joule is clearly 10^{7} ergs and the watt 10^{7} ergs per second.

Electrical Horse-Power.—One horse-power is, as is well known, a power of 33,000 foot-pounds per minute, or 550 foot-pounds per second; or, as one foot-pound = .1385 kilogrammetres, a power of 76 + kilogrammetres per second. As a gramme centimetre = 981 ergs, a kilogrammetre = $981 \times 1{,}000 \times 100 = 98{,}100{,}000$ ergs = 9.81×10^{7} ergs; so that one horse-power = $76 \times 9.81 \times 10^{7} = 746 \times 10^{7}$ ergs per second. Therefore the number of horse-power developed by C ampères falling through E volts =

$$HP = \frac{CE \times 10^{7}}{746 \times 10^{7}} = \frac{CE}{746};$$ per second.

words, it equals the number of watts divided by 746. One horse-power, then, = 746 watts. per second

By the above formula the horse-power developed in a whole circuit can be calculated by taking E as the whole difference of potential, or, in other words, the E. M. F. of the generator; and the horse-power in any portion of the circuit by taking as E the difference in potential of the two extremes of that portion. For this latter purpose, however, it is usually more convenient to change the form of the equation.

As $C = \frac{E}{R}$, the current in any portion of a circuit is equal to the difference in potential of the extremities of that portion divided by the resistance of that portion. Therefore the formula $\frac{CE}{746}$ may be written $\frac{C^2R}{746}$ or $\frac{E^2}{R \times 746}$. The first formula we recognize as being the same one as that deduced before in calculating the heating effects of currents; so that we may consider the work done in any circuit as the heat developed in it. The following table, published by the author in the New York *Electrician*, and reprinted with the kind permission of the editors, shows the relative values of the units employed in practice in this country and in England, and those used in France, belonging to the "C. G. S." (centimetre, gramme, second) system:

1 Gramme = 15.432 grains.
1 Gramme = 981 dynes.
1 Pound = 445,900 dynes (approximate).
1 Dyne = .00000224+ lbs. (approximate).
1 Grain = .0648 grammes.
1 Metre = 39.37 inches.
1 Kilometre = 1093.6 yds.
1 Erg = 1 dyne-centimetre.
1 Foot-pound = 13,586,850 ergs of work = 13+ megergs.

1 Foot-pound = .1385 kilogrammetres. Meg = 1 000 000
1 Kilogrammetre = 98.1 megergs.
1 " = 7.220 foot-pounds.
1 Volt = 10^8 C. G. S. units.
1 Ohm = 10^9 " "
1 Ampère = 10^{-1} C. G. S. units.
1 Coulomb = 10^{-1} " "
1 Farad = 10^{-9} " "
1 Calorie = 42×10^6 ergs = 1 gramme water 1° C.
1 English heat-unit = 772 foot-pounds = 1 lb. water 1° F.
1 Horse-power = 550 foot-pounds per second.
1 " " = 33,000 foot-pounds per minute.
1 " " = 1,980,000 foot-pounds per hour.
1 " " = 76 kilogrammetres per second, English measure.
1 Horse-power = 75 kilogrammetres per second, French measure.
1 Horse-power = 7,460 megergs per second, English measure.
1 Horse-power = 7,357.5 megergs per second, French measure.
Unit of electrical *work* = volt-coulomb, or joule.
1 Joule = .737 foot-pounds.
Unit electrical power = volt-ampère, or watt.
1 Watt = 10 megergs per second = $\frac{1}{9.81}$ kilogrammetres per second = $\frac{1}{746}$ horse-power. per second

Transmission of Power.—In any system for transmitting power from one point to another the power wasted in overcoming the resistance of the conductor, expressed by the formula C^2R, or $\frac{E^2}{R}$, is of the greatest consequence. As electrical power is composed of the two factors C and E, we can make C or E as large or small as we choose, provided that we keep their product constant. A casual inspection of the formula $\frac{E^2}{R}$ might

lead to the hasty conclusion that in order to transmit power with small loss *in transitu* it would be best to make E as small and R as large as possible; that is, to use a dynamo generating a low electro-motive force, and a conductor of great resistance. But in this formula E, as said above, does not mean the E. M. F. of the machine, but only the difference of potential between the extremities of the resistance R. Bearing this in mind, we are led directly to a contrary conclusion, for we see that the electro-motive force of the dynamo must be large and the resistance of the conductor small, because then E, the difference of potential between the ends of the resistance R, will be very small; and, as E enters in the formula by its square and R by its first power, it is more important to have E small than R. A more satisfactory explanation of the necessity for using a high electro-motive force can be found by considering the formula C^2R, which shows at once that the waste energy increases as the square of the current and the first power of the resistance.

In the case of a dynamo transmitting power to an electro-motor which develops a counter E. M. F. = E′, the resultant electro-motive force is E—E′; and letting R represent the sum of all the resistances of the entire circuit, the loss of energy in overcoming R will be

$$\frac{(E-E')^2}{R}.$$

As long, then, as we keep $E-E'$ and R constant the loss of heat will be the same; and, no matter how large we make R, the loss of heat will not be altered if we proportionally change $(E-E')^2$. Thus we see that we can theoretically transmit any power over any distance, if we can produce a sufficiently high electro-motive force, in both dynamo and motor, to allow of using a small current. In transmitting power by electricity on a large scale one of the first things to be calculated is the current which

the conductor will stand without so heating as to occasion undue loss of power. The following tables of the amount of horse-power lost per thousand yards in conductors of different sizes, with currents of different strengths, have been published by the English *Electrical Review* from calculations made by Robert Sabine, C.E.

Radiation of Heat by Conductors.—The radiation of heat by a heated conductor is an important consideration also, for the reason that the heat developed, if not allowed to escape, will increase the resistance of the conductor, thereby increasing the development of heat, which will still further increase the resistance. For this reason it would be better, where it is possible, to have the conductor naked and extended upon poles than to have it surrounded with insulating material and buried in the earth. It would also be better to have it composed of a number of small wires than of one large conductor of equal area, on account of their greater radiating surface.

Different Systems of Electric Distribution.—In the case just considered the problem was simply to transmit a certain amount of power by a single conductor, but it bears upon a somewhat more complicated problem—that of distributing power or light, or both, to a great number of lamps and motors by means of a great number of conductors. This is the condition of affairs to be met in attempting to supply light and power to a city.

All of the systems as yet proposed may be divided into seven general classes: the series, the multiple, the multiple-series, the series-multiple, the accumulator, the motor-dynamo, and the induction systems. Each system has its advantages and its disadvantages; and as hardly any one can be said to present a wholly satisfactory solution of the question, it seems probable that some method combining two or more of them may be ultimately adopted.

Series System.—In the series system the lights and

I.—For Currents from 5 to 1,000 Ampères, Conductors of Bright Copper.

Diameter of Conductors.	5a		10a		20a		30a		40a		50a		60a		70a		80a		90a	
	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1 000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.
Inch.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.
.04	.89	38	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.05	.49	19	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.06	.36	12	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.07	.24	7	1.03	29	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.08	.18	4	.76	18	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.09	.15	3	.55	12	2.4	49	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.1	.11	2	.45	9	1.9	36	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.11	.09	2	.36	7	1.5	27	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.12	.076	1	.31	5	1.3	21	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.13	....	...	.26	4	1.1	17	3.1	47	....	...	....	...	....	...	....	...	....	...	....	...
.14	....	...	.22	3	.91	13	2.5	36	3.9	51	....	...	....	...	....	...	....	...	....	...
.15	....	...	.19	2	.79	10	2.0	29	3.4	41	....	...	....	...	....	...	....	...	....	...
.2	....	...	.11	1	.45	5	1.9	23	1.9	18	3.0	31	4.4	41	....	...	....	...	....	...
.25	....	...	....	...	.26	2	1.0	11	1.1	9	1.8	13	2.6	19	3.7	27	4.8	36	6.0	44
.3	....	...	....	...	.20	1	.60	5	.78	5	1.2	8	1.8	12	2.5	16	3.2	21	4.2	26
.35	....	...	....	...	.15	1	.44	3	.60	3	.92	5	1.3	7	1.8	10	2.5	13	3.0	17
.4	....	...	....	...	....	...	.33	2	.43	2	.67	4	.97	5	1.3	7	1.7	9	2.3	12
.45	....	...	....	...	....	...	.24	1	.34	2	.53	3	.72	4	.94	5	1.4	7	1.7	8
.5	....	...	....	...	....	...	.18	1	.29	1	.45	2	.64	3	.88	4	1.1	5	1.4	6
.55	....	...	....	...	....	...	....	...	.24	1	.37	1	.53	2	.73	2	.95	3	1.2	4
.6	....	...	....	...	....	...	....	...	....	...	.28	1	.40	1	.54	2	.70	3	.90	3
.65	....	...	....	...	....	...	....	...	....	...	....	...	.36	1	.49	1	.64	2	.87	3
.7	....	...	....	...	....	...	....	...	....	...	....	...	....	...	.45	1	.57	2	.72	2
.75	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	.62	2

Diameter of Conductor.	100a		200a		300a		400a		500a		600a		700a		800a		900a		1,000a	
	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.	Power absorbed per 1,000 yards.	Approximate rise of temperature.
Inch.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.	H. P.	Deg. Fah.
.25	7.3	49	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.30	4.8	29	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.35	3.4	18	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.40	2.8	13	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.45	2.1	10	9.3	37	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.50	1.8	8	7.7	29	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.55	1.4	6	5.8	22	....	...	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.60	1.2	4	4.9	16	11.8	40	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.65	1.0	3	4.2	14	9.8	28	....	...	....	...	....	...	....	...	....	...	....	...	....	...
.70	.97	3	3.9	12	9.1	23	16.8	41	....	...	....	...	....	...	....	...	....	...	....	...
.75	.78	2	3.1	9	7.3	18	13.3	32	21.9	50	....	...	....	...	....	...	....	...	....	...
1.00	.45	1	1.8	3	4.1	8	7.5	14	11.8	21	17.7	39	....	...	....	...	....	...	....	...
1.25	....	...	....	...	2.6	4	4.3	7	7.3	11	10.5	16	14.6	22	19.4	29	25.1	36	31.6	44
1.50	....	...	....	...	....	...	3.4	5	5.0	7	7.2	10	9.9	14	14.2	18	16.6	23	20.9	29
1.75	....	...	....	...	....	...	....	...	3.5	5	5.0	7	7.0	10	9.0	13	11.7	16	14.6	20
2.00	....	...	....	...	....	...	....	...	....	...	3.8	5	5.2	7	7.0	9	8.8	11	10.9	14
2.25	....	...	....	...	....	...	....	...	....	...	....	...	....	...	5.5	6	7.1	7	8.8	9

motors are placed one after another upon a circuit, the current traversing each in turn (Fig. 157).

Fig. 157.

Multiple-Arc System.—In the multiple-arc system the lamps and motors are placed in multiple arc, and each is connected by two wires with two large mains coming from the poles of the dynamo (Fig. 158). In extended

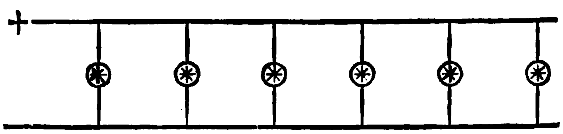


Fig. 158.

systems, like that of Mr. Edison in New York, these mains are fed by two large feeders, instead of coming direct from the machine.

The Multiple-Series and Series-Multiple Systems.—These systems may be said to be combinations of the two preceding. In the multiple-series system a number of lamps are placed in series in a circuit leading from one main to the other (Fig. 159), and in the series-

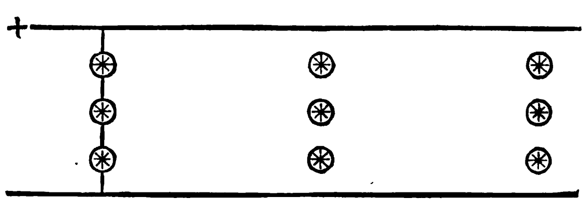


Fig. 159.

multiple system the main circuit divides into a number of branches, each containing a number of devices in series (Fig. 160), the branches again reuniting after

passing through said devices. Farther on, at the next house, for instance, the current is again slit into branches as shown.

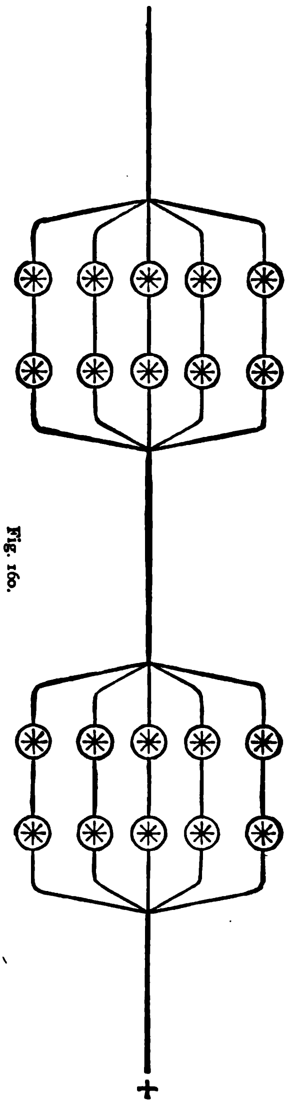


Fig. 160.

The Accumulator System.—In this system the devices for any space—a house, for instance—are placed in multiple arc and are fed direct from accumulators near at hand, the accumulators being fed by a charging circuit containing many similar groups of accumulators, and proceeding from a high-tension dynamo.

Motor-Dynamo System.—In the motor-dynamo system the arrangements are much the same, except that motors actuating dynamos take the place of accumulators. The motors are placed in series upon a long, charging circuit, and caused to revolve thereby. Each motor is mechanically connected to a dynamo, which, in revolving, generates a current and feeds devices placed in multiple arc. In some motor-dynamo systems the armature of the motor has two coils and two collectors and two pairs of brushes; one coil, collector, and pair of brushes being in the main circuit, the other coil, collector, and pair of brushes being in the lamp circuit, so that the same magnet-coils suffice for both the motor and the dynamo.

Induction System.—In the induction system the main (alternating current) traverses the primary of an induction-coil, whose secondary is in the lamp circuit (Fig. 161). In the system of Messrs. Gaulard and Gibbs, which

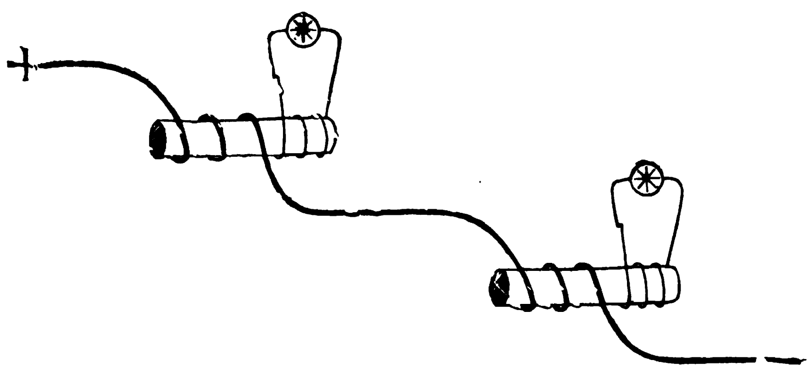


Fig. 161.

is an attempt to reduce the induction system to practice, the secondary coil is divided into a number of sections which can be united either in series or multiple arc, so that the secondary current is under the control of the person using it. In Figs. 162, taken from *Engineering*, I. is a perspective view of their apparatus, II. a longitudinal section of one of the coils, and III. a diagram of an installation of dynamo and secondary generators. On each of the four cylinders are wound both the primary and the secondary wires. The secondary wires of the four columns are connected to the commutator shown at the top, so that the current from each column may be taken off separately, or so the currents from any two or more may be united either in series or in multiple arc. It is stated that two of these generators, in series, have been fed by an alternating current of thirteen ampères, and that one of them produced a secondary current which fed twenty-six incandescent lamps, while the other fed from

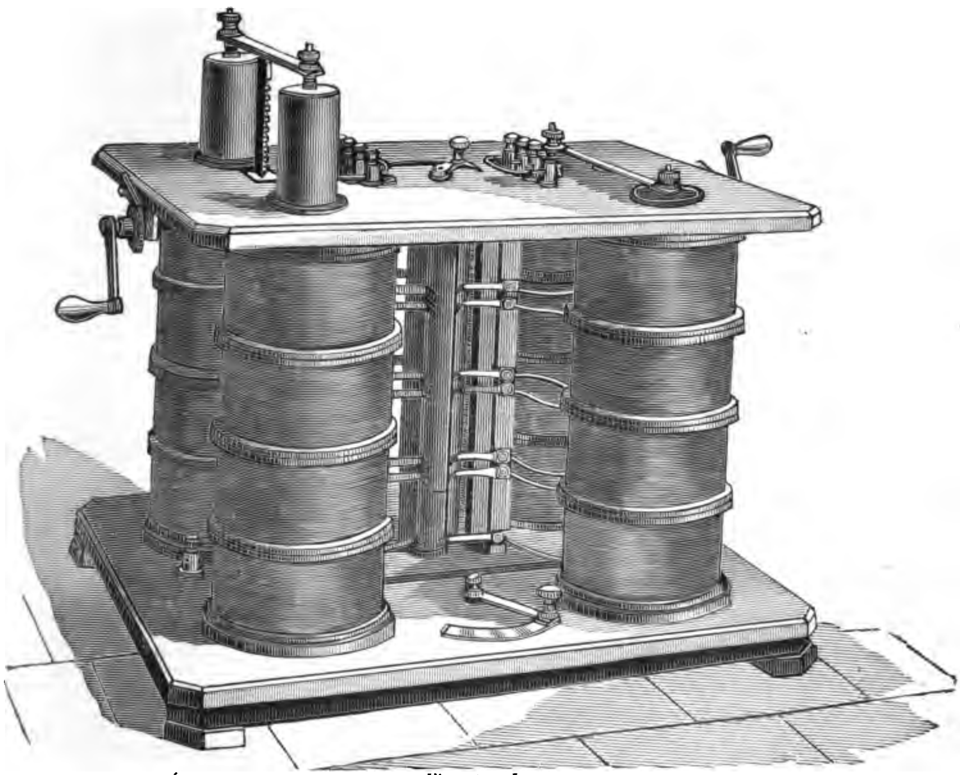


Fig. 162.—I.

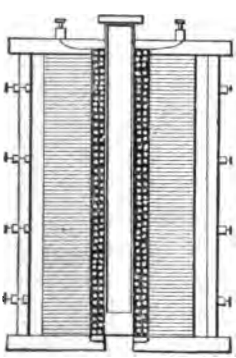


Fig. 162.—II.

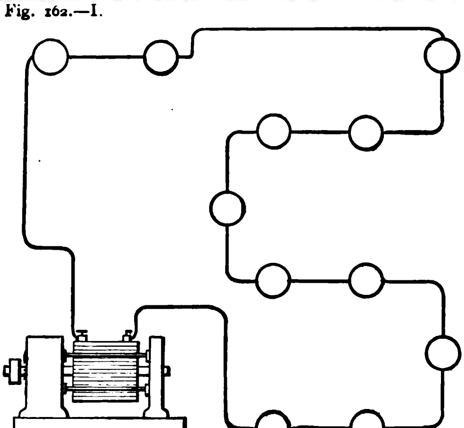


Fig. 162.—III.

one column five Swan lights, from another a motor, and from the other two, in series, a Jablochkoff candle. By lowering or raising the iron cores inside each column the strength of the secondary current can be increased or diminished at will.

Mr. Edison has patented an induction system in which an "induction apparatus is located between the main circuit and the translating devices, and transforming a continuous current of high tension into a continuous current of lower tension by the employment of a magnetic core or cores having two sets of wire coils, one of high resistance connected with the main circuit, and one of lower resistance connected with the consumption circuit, the connections of the main and consumption circuits with their respective sets of coils being changed or advanced simultaneously, so that the inductive action of the magnetic core or cores will cause the current to flow in the consumption circuit always in the same direction."

The object of this invention is to secure the benefit of a small current of high tension in the main circuit, and a current of small tension in the lamp circuits.

Advantages and Disadvantages of Each System.—If considered from the standpoint of economy alone, the *series system* possesses great advantages over the others, from the fact that where devices are placed in series the current required to feed all is merely that required to feed one. This does not mean that it is as cheap to supply all as to supply one, for it is evident that the resistance of the circuit increases with the number of devices placed in it, so that the generator must do more work, because it must generate a higher E. M. F. But as the loss in the conductor varies as the square of the current, it is clear that a comparatively small conductor may be used—a great item when the high cost of copper is considered. The disadvantages of a series system are that each device is dependent for its supply upon the in-

tegrity of the whole system (for a break in any part of the circuit stops the whole current), and that a current of the enormous E. M. F. that would be needed to overcome the great resistance of an extended circuit could hardly be restrained by any known insulation, and, in a thickly settled district, would be dangerous to life and property in the highest degree.

In the *multiple-arc system* we find a state of affairs exactly the reverse. In this system, as each device gets its current direct from the mains, a very low electro-motive force will suffice, being merely that necessary for one device, and each device is independent of all the others. By reason of these advantages, and on account of the simplicity of the arrangement and of the ease with which any device may be removed or repaired, the multiple-arc systems are much more popular than the others. They have, however, the very great disadvantage that the cost of the plant is very great by reason of the enormous feeders and mains which are necessary. As each lamp and motor gets its current independently of the others, the current carried by the feeders must be equal to the sum of all the currents, and the current carried by the mains must be the sum of all the currents for the lamps fed from them. The heating effect of the current being proportional to the square of the current and the first power of the resistance, it becomes of the greatest importance to keep down the resistance of the mains and feeders. As copper is the only suitable material for carrying large currents, and as its cost is very high, the effect of increasing the size of copper conductors in order to carry large currents is to increase the first cost of the plant, and therefore the interest thereon.

The *series-multiple* and *multiple-series systems* endeavor to combine the economy of the series systems with the safety and reliability of the multiple-arc systems, but, as yet, not very satisfactorily. Evidently, however, they

are exceedingly flexible and admit of such numerous modifications that some system may be derived from them which will produce the desired result. The most promising seems to be that recently patented by Mr. Edison. It is a form of the multiple-series system, in which the source of electrical power is divided into as many parts as there are devices in each series between the mains, and in which compensating conductors run from points between each two divisions of the source of power through points between each corresponding pair of devices. If, for instance, two devices are placed in series between the mains, the electro-motive force between the mains can be doubled, and therefore the current in them halved.

In the *accumulator system*, as a high electro-motive force is used in the charging circuit, the current needed in the charging conductors may be small, so that comparatively small wires may be used. A circuit of this kind may be made quite safe, also, if the accumulators and charging conductors are kept out of the way.

The devices within a house being supplied in multiple arc, the electro-motive force of the current in the house-wires will be low and safe; and as accumulators discharge more steadily than a dynamo can be turned, the lamps supplied will glow with an absolutely unflickering light. The great disadvantage of the accumulator system is that, in the present state of the art, they are very expensive and very heavy, that they furnish individually so small a current that many are needed to supply one incandescence lamp, and that they do not return a large percentage of the work stored in them. In future, doubtless, these faults may be remedied to a great extent.

In the *motor-dynamo system* it is proposed to have each motor-dynamo supply a district of such size that its conducting mains will not be very large, on the one hand, and that too great a number of motor-dynamos for a

whole circuit will not be required, on the other hand. The advantages of this system, like those of the accumulator system, are obvious. But it remains to be seen whether the losses of energy in the circuit will be too great to destroy its practicability. Clearly there is a twofold loss at each motor-dynamo: the loss from converting the electrical energy of the current into the mechanical energy of the motor, and the loss from converting the mechanical energy of the motor into the electrical energy generated by the dynamo actuated thereby. The cost of the motor-dynamos is also, of course, to be calculated.

The *induction systems* have the advantage of flexibility, but it remains to be seen whether the secondary currents can be induced without too great loss to allow of such a system being economically operated. In the apparatus of Gaulard and Gibbs great stress is laid by the projectors upon the fact that the tension of the current can be regulated to suit the demands of the user.

That this is an advantage may well be considered doubtful, however, when it is remembered that high-tension currents are of necessity dangerous, and that a system should be such that an ignorant person cannot be injured by any of the apparatus. The regulations of the Board of Trade in England, limiting the E. M. F. to four hundred volts, would seem judicious, and the advisability of supplying the devices within houses at an unvarying and low tension would seem obvious when all the conditions of the question are impartially considered.

Maintenance of Constant E. M. F.—In the *multiple-arc system*, as the resistance of each device remains constant, and it is necessary to maintain through it a uniform current, the problem is to preserve an unvarying difference of potential between the conductors, and therefore the mains and the feeders, no matter how

many lamps are added to or subtracted from the circuit.

Were it not for the resistance of the machine itself, this would be an easy matter; for, supposing the feeders to be at the proper difference of potential, the addition of more lamps would merely lower the resistance of the external circuit and increase the strength of current correspondingly. But as every machine possesses a certain resistance, the decrease in the external resistance decreases the proportion of potential furnished the circuit and increases the amount consumed in the machine, so that the electro-motive force of the machine must be increased until the difference of potential of the conductors is raised to the proper amount. In the Edison system this is accomplished by increasing the magnetization of the field-magnets (shunt) by removing therefrom a certain resistance. An attendant watches the burning of a lamp and the needle of a galvanometer. If the needle shows a decrease of current—*i.e.*, a fall of potential—he takes out some of the resistances in the field-magnet coils, and when the needle shows an increase he introduces additional resistances. The resistances lie in large, square boxes, and are connected to projecting metal strips on the circumference of a circular commutator. A metal arm, pivoted in the centre, can be moved around the face of the commutator, touching the metal strips in turn, and so cutting out or in whatever resistances are desired.

When several machines are coupled in multiple arc the commutators corresponding to the different machines can be operated simultaneously by means of a long bar mounted horizontally and gearing into wheels operating the arm of each commutator. The bar may be revolved about its longitudinal axis by means of a large wheel, and the resistance of the coils of all the machines controlled thereby. Many plans have been patented for accomplishing automatically this changing of resistance, but in practice it

has been found so easy for an attendant to do it that it has not been deemed advisable to resort to the necessary complication of an automatic apparatus, though they are used in some plants, such, for instance, as that on board the steamer *Pilgrim*.

When lamps and motors are fed in multiple arc the potentials supplied to all of the lamps are not the same, even under the most favorable circumstances, but vary with the distance from the generator to the points from which the lamps draw their supply. Clearly a lamp near the generator will get the benefit of nearly the whole potential furnished to the circuit, for the reason that it takes one wire from very near the positive pole of the generator, and the other from very near its negative pole, while the case of the lamp farthest away is manifestly different. This lamp takes one wire from a point where the potential is less than at the positive pole, and the other from a point where the potential is greater than at the negative pole. In order that the difference of potential furnished lamps and motors may vary as little as possible, it is clear that the resistance of the mains should be made as small as possible.

Size of Conductors.—For the reason that if the mains and feeders of a system are too small there will be great loss of energy in carrying the necessary current, and for the reason, on the other hand, that if conductors are made unnecessarily large the cost of the plant will be unnecessarily increased, it is a matter of great practical importance to determine the best size of conductor for carrying any current. The rule given by Sir William Thomson is that the most economical diameter of conductor is secured when the two losses (*i.e.*, the loss from heating and the interest upon the price of the conductor) are equal. Knowing the cost of one horse-power of electrical energy in the locality—which depends upon the price of coal and the efficiency of the machinery—and the

cost of copper per ton, and remembering the formula $HP = \frac{C^2R}{746}$, the calculation for that locality can be readily made.

Generative Efficiency of Machines.—By this term is meant the proportion of the electrical energy generated by the machine to the mechanical energy applied to turn the armature, the most efficient machine being, of course, that one rendering the largest percentage in return. In order to secure an efficient machine it is not only necessary to look to the mechanical details, such as the avoidance of useless friction, the balancing of the armature, etc., but it is also necessary to prevent the heating of the armature-coils to as great an extent as possible, and to avoid Foucault currents in the armature-core and the pole-pieces of the field-magnets. The following rules for constructing efficient machines are given by Prof. Silvanus P. Thompson in his admirable "Cantor Lectures":

The field-magnets should be heavy, long, and made of as soft iron as possible.

The pole-pieces should be heavy and have plenty of iron in them. In the magnets and pole-pieces sharp corners and edges should be avoided as far as possible. In order to avoid Foucault currents in the pole-pieces they should be built up of laminæ, so placed that their planes are perpendicular to the direction of the currents.

The field-magnet coils should be wound on most thickly at the middle of the magnets. The armature-cores should be constructed with a view to avoiding Foucault currents, and therefore they should be made of thin discs of iron separated by sheets of some insulating substance, like asbestos-paper, the planes of the discs being parallel to the lines of force, and therefore perpendicular to the direction of the Foucault currents. The resistance of the armature should be as small as possible, without sacrificing electro-motive force or requiring undue driving speed. In order to

generate a current as continuous as possible the armature-coils ought to be divided up into a large number of sections, each coming in regular succession into the position of best action.

Lead of Brushes.—In consequence of the magnetic lines of force surrounding the wires of an armature the direction of the lines of force running between the magnet-poles is modified. In Fig. 163, which represents a pair of conductors traversed by a current perpendicular to the plane of the figure, which rises in the right-hand conductor and descends in the left, the encircling lines of force, running as shown, attract and repel the other lines of force which run from the north pole, N, to the south pole, S. Supposing the two conductors to be conductors on an armature, it is clear that the positive direction of the lines of force running through the armature will not be in the straight line from N to S, but will be in the oblique direction shown. This phenomenon explains the necessity for giving a certain "lead" or angular advance to the brushes of dynamos and motors; for the brushes should touch the collector at the points of highest and lowest potential, and the angular change of direction of the lines of force produces an equal angular change in the position of these points. As the amount of change of direction of the lines of force depends upon the magnetic swirls around the conductors, it is clear that the greater the current in these conductors, as

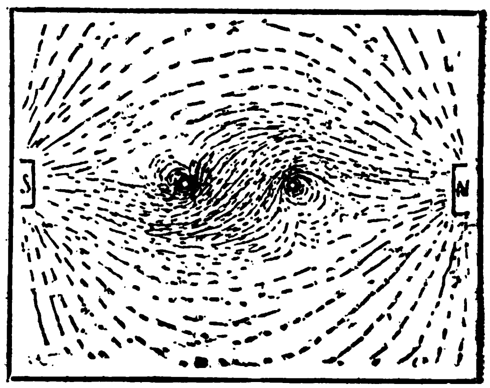


Fig. 163.

compared with the strength of the poles, the greater will be the lead of the brushes necessitated. For the same reason it is clear that the greater the speed of a given dynamo, after the magnets have approached their point of saturation, the greater the lead that must be given to the brushes; while with a motor the reverse is the case. In a motor, it will be remembered, the greater the speed of rotation the less the current in the armature, because the greater the counter E. M. F. set up; so that the greater the speed the less the amount of lead required. The direction of this lead is, of course, the reverse of that in a dynamo turning in the same direction.

See Ans. p. 4

Electrical Efficiency of Machines.—Besides the generative efficiency of a machine, there is also to be considered its electrical efficiency, or the proportion borne by the electrical energy furnished the external circuit to the total electrical energy generated. It being clear that the electrical energy consumed in the machine is, for practical purposes, wasted, it becomes necessary to reduce this amount to a minimum, and therefore to first understand upon what conditions it depends.

The most simple case is that of the magneto-machine. Denoting the resistance of the armature by a, and that of the external circuit by r, and remembering that, as the strength of current is alike in both, the power furnished to the armature and the external circuit must vary with the potentials due to their resistances, which must, from what we have before seen, vary as those resistances, we see that

$$F = \frac{r}{a + r},$$

in which F is the efficiency.

Thus we see that the smaller the ratio $\frac{a}{r}$ the greater the efficiency of a magneto-machine, so that all useless resistances in the armature-coils should be studiously

avoided. In the case of a separately-excited dynamo the same formula would apply as far as the armature is concerned, and therefore the same conclusion would be reached. The conditions governing the excitation of the field-magnets would vary according to the nature of the exciting source, whether it were a dynamo, a voltaic battery, or a battery of accumulators. In calculating the efficiency of the machine, however, the energy in the armature-coils and circuit would have to be calculated from the formula $C^2(a+r)$, in which a is the resistance of the armature and r the external resistance; and to this would have to be added the total energy expended in the exciting circuit, calculated by the formula C'^2R', in which C' is the strength of the exciting current and R' the resistance of the exciting circuit. Letting $F =$ the efficiency of the machine, C the current, and r the external resistance,

$$F = \frac{C^2 r}{C^2(a+r) + C'^2 R'}.$$

In the case of a series dynamo, in which the same current traverses the armature, field-magnet coils, and external circuit, the energy must divide itself in the ratio of the resistances, so that

$$F = \frac{r}{a+m+r},$$

in which r is the resistance of the external circuit, a that of the armature, and m that of the field-magnet coils.

In this case we see the necessity of reducing, as far as consistent with a sufficiently high E. M. F., the resistance of both the armature and the field-magnet coils.

In a shunt dynamo the current in the armature is clearly the sum of the currents in the external circuit and the magnet-coils, supposing the shunt to be taken directly from the brushes.

Let C = current in the armature; then the current in the main circuit must, by the law of branch circuits, be

$$C\frac{m}{m+r},$$

and the whole resistance of the circuit

$$R = \frac{mr}{m+r} + a$$

$$\therefore\ F = \frac{\left(C\frac{m}{m+r}\right)^2 r}{C^2\left(\frac{mr}{m+r}+a\right)} = \frac{m^2 r}{a(m+r)^2 + m^2 r + mr^2}.$$

In this case the best relative resistances of the armature, external circuit, and field-magnets are less obvious, and require a separate calculation.

Taking the reciprocal of the above equation, in order to put it in a more convenient form for differentiating, and remembering that the maximum of the reciprocal of F is the minimum of F, and *vice versa*,

$$\frac{1}{F} = F' = \frac{a(m+r)^2 + m^2 r + mr^2}{m^2 r} =$$

$$\frac{am^2 + 2amr + ar^2 + mr^2 + m^2 r}{m^2 r} =$$

$$\frac{a}{r} + \frac{2a}{m} + \frac{ar}{m^2} + \frac{r}{m} + 1. \quad (1)$$

Differentiating, r being considered the variable,

$$dF' = \frac{-adr}{r^2} + \frac{adr}{m^2} + \frac{dr}{m}. \quad (2)$$

$$\frac{dF'}{dr} = \frac{-a}{r^2} + \frac{a}{m^2} + \frac{1}{m}. \quad (3)$$

$$\frac{d^2F'}{dr^2} = \frac{+2ar}{r^4} = \frac{+2a}{r^3}. \quad (4)$$

Equating the second term of (3) to zero,

$$\frac{a}{r^2} = \frac{a}{m^2} + \frac{1}{m},$$

$$am^2 = ar^2 + r^2m,$$

$$r^2(a + m) = m^2a,$$

$$r^2 = \frac{m^2a}{a + m} = m^2\frac{a}{a + m},$$

$$r = \pm m\sqrt{\frac{a}{a + m}}.$$

The positive value of r makes (4) positive, and therefore corresponds to a minimum value of F′, and consequently to a maximum value of F.

The case of a dynamo whose magnet-coils are wound partly in series and partly in shunt is quite similar. It is obvious that the formula for the proportion of energy consumed in the external circuit plus that consumed in the series coils (supposing the shunt to be taken direct from the brushes) may be taken from the above formula by simply substituting r' for r, in which r' represents the sum of the resistances of the external circuit and the series coils:

$$\therefore\ F' = \frac{m^2r'}{a(m + r')^2 + m^2r' + mr'^2}$$

Letting r, as before, represent the resistance of the external circuit, we have

$$F : F' = r : r',$$

$$\therefore\ F = \frac{F'r}{r'},$$

and

$$F = \frac{m^2r}{a(m + r')^2 + m^2r' + mr'^2}.$$

Efficiency and Maximum Power of Motors.— It will be remembered that, in speaking of grouping cells, it was said that the maximum effect of any given number of cells over any circuit is obtained by so arranging the cells that their internal resistance is equal to the external resistance of the circuit; and it will be also remembered that the researches of the Count du Moncel have proved that with a given battery and an electro-magnet of given dimensions the maximum effect can be got out of the magnet when wire is used such that it makes the resistance of the coils equal to that of the exterior circuit.

Jacobi's law of the maximum effect of electro-motors indicates a like principle, for it declares that "the mechanical work done by an electro-motor is at a maximum when it is geared to run at such a speed that the current is reduced to one-half what it was when the motor was at rest."

In running motors, however, there are other conditions to be considered than that of maximum work alone, the principal one being that of economy or efficiency. For just as a man would not think it economical to always work a horse to the very limit of his strength, so a man understanding the principle of an electro-motor would not think it economical to always run an electro-motor at the utmost limit of its strength.

In working an electro-motor the aim should be to get as much work as possible per horse-power of the engine turning the dynamo.

As the counter-current set up by an electro-motor weakens the current from the dynamo, and therefore cuts down the expenditure of coal, it would seem that the faster the electro-motor revolved the more economical it would be, and that the maximum of economy would be reached when (supposing the motor and dynamo to be equal and similar) the motor was revolving as fast as the

dynamo. In this case, however, the expenditure of coal would be theoretically zero, and, therefore, at the same time the amount of work performed would be also zero.

Thus we see that, to work a motor satisfactorily, a middle course must be pursued. In other words, we must select some speed of rotation for the motor, such that the current shall be less than half of what it is when the motor is stationary, and yet large enough to allow of considerable work being done. Dr. Siemens gives the rule that, in practice, "the best condition of working consists in giving to the primary machine such proportions as to produce a current of the same magnitude, but of fifty per cent. greater E. M. F. than the motor." Supposing the dynamo and the motor to be of the same dimensions, we can say roughly that the motor should revolve at a little less than two-thirds of the speed of the dynamo. In case it is not desirable to have the machinery operated by the motor revolve so fast, the motor should be connected to it by reducing gear.

In order to arrive at an expression for the efficiency of an electro-motor, let the E. M. F. of the dynamo when the motor is at rest be E, and that of the motor E′. Letting the resistance of the circuit be R, the strength of current in the first case, when the motor is at rest, will be

$$C = \frac{E}{R},$$

and in the second case, when the motor is in motion, and generates the counter E. M. F., E′,

$$C' = \frac{E}{R} - \frac{E'}{R} = \frac{E - E'}{R}.$$

Let the whole work done per second in the circuit, both by the heating of the circuit and the revolution of the motor, be W, and that done by the motor alone W′.

Then W must be equal to W′ plus the waste heating of the circuit; or,

$$W = W' + \frac{(E - E')^2}{R}. \quad (1)$$

But $W = E \times \frac{E - E'}{R}$ (2), the product of its E. M. F. by the current, C′.

$$\therefore E \times \frac{E - E'}{R} = W' + \frac{(E - E')^2}{R} \quad (3)$$

$$W' = \frac{E(E - E')}{R} - \frac{(E - E')^2}{R} = \quad (4)$$

Dividing (4) by (2),

$$\frac{W'}{W} = \frac{\frac{E(E - E') - (E - E')^2}{R}}{\frac{E \times (E - E')}{R}} = \frac{E - (E - E')}{E} = \frac{E'}{E}.$$

In other words, the efficiency of a motor at any given speed is represented by the E. M. F. developed by the motor at that speed divided by the E. M. F. of the dynamo.

In order to find the conditions for making W′ a maximum, we get from (4)

$$W' = \frac{E^2 - EE' - E^2 + 2EE' - E'^2}{R} = \frac{EE' - E'^2}{R}$$

Differentiating with reference to E′,

$$\frac{dW'}{dE'} = \frac{E - 2E'}{R} = O,$$

$$E = 2E' \therefore \frac{E'}{E} = \tfrac{1}{2};$$

showing that when we get the maximum work out of a motor the efficiency is only one-half. As the resistance of the circuit is constant and $E' = \frac{E}{2}$, the current is then half of what it is with the motor at rest.

In all these formulas W′, it need not be said, signifies the electrical work of the motor per second—*i.e.*, C′E′. The amount of mechanical work this produces depends upon the electrical efficiency of the motor—*i.e.*, the ratio of the mechanical to the electrical work. With a good motor this may be said to be about eighty-five per cent. *

Arrangement of Accumulators.—In an accumulator system it will be necessary to compute the number and best arrangement of accumulators having each an E. M. F., e, for supplying a given number of incandescence lamps, n, having each a resistance, r', when hot; the potential necessary for each lamp being e'.

The whole current necessary, then, is

$$C = n\frac{e'}{r'}.$$

Suppose the current which each cell can furnish *economically* is c. Then we must have such a *number of series* of cells that the whole current shall be C. Letting y = this number of series,

$$y = \frac{C}{c}.$$

Let x = number of cells in each series.
Let r = resistance of each cell.
Let R = resistance of conductors.

* For a more detailed exposition of the laws governing electro-motors and dynamos the reader is respectfully referred to the admirable "Cantor Lectures" of Prof. Silvanus Thompson, and to the reports of the lectures of Sir Wm. Thomson, Profs. Ayrton and Perry, Drs. Siemens, Hopkinson, and others, published in the English *Electrical Review* and *Electrician*.

Then

$$C = \frac{xe}{\frac{xr}{y} + \frac{r'}{n} + R} = \frac{xeny}{nxr + r'y + Rny}$$

$$Cnxr + Cr'y + CRny = xeny.$$

$$x(eny - Cnr) = Cr'y + CRny.$$

$$\text{But } C = \frac{ne'}{r'} \quad \therefore n = \frac{r'C}{e'}$$

$$\therefore x(ey - Cr) = e'y + CRy$$

$$x = \frac{(e' + CR)y}{ey - Cr}.$$

CHAPTER XVII.

METERS.

IN any general system of electric distribution in which consumers are supplied with light and power by a company for a compensation, it is clearly essential to have some measure by which to calculate the proper amount of compensation.

At first sight it might seem that a voltameter would satisfy every requirement, since a voltameter will indicate the amount of electricity that has passed in any interval. But as the amount of electricity that has passed through any part of a circuit is no measure of the amount of work performed, unless it is accompanied by an indication of the resistance through which it is forced or the potential through which it falls (C^2R, $\frac{E^2}{R}$, CE), an instrument, to be satisfactory, must either show directly the number of units expended or else must show it indirectly by indicating some function of the work performed. To this latter class belongs the meter of Mr. Edison, which is merely a form of voltameter, but which, when used in his system, gives a measure of the work, for the reason that the electricity is supplied to consumers at a nearly constant potential.

Edison's Meter.—This meter, represented in Fig. 164, consists of two cells, containing each two zincs standing in solutions of sulphate of zinc, secured in a cast-iron box and resting upon a shelf, below which is placed an ordinary Edison lamp. The cells are in a shunt from one

of the conductors leading into the building whose supply of current the meter is to measure, but the resistance of the conductor between the attachments of one cell is three or four times that of the conductor between the points of attachment of the wires of the other cell, so that the current traversing the first cell is proportionally greater than that traversing the second.

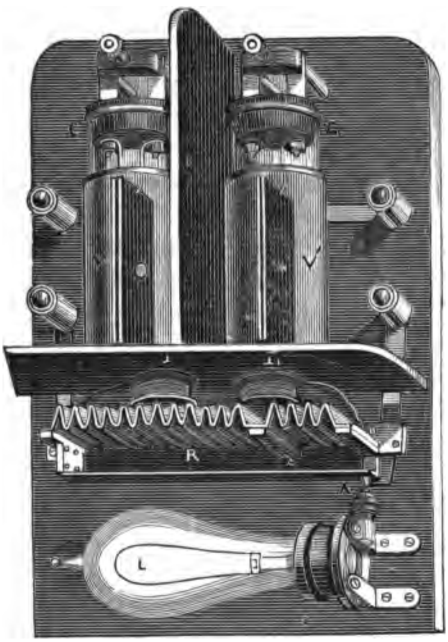


Fig. 164.

The object of the second cell is to give a check upon the indications of the first. At the end of each month the employees of the company remove the zincs from the first cell, replacing them with fresh ones, and take them to the central station, where they are weighed. As the current goes from one zinc to the other, the anode decreases and the cathode correspondingly increases in weight, so that by measuring the amount of increase or decrease, and knowing the amount of deposit of zinc per coulomb (.0003412 gramme), an indication is at once secured of the amount of electricity that has passed through the subscriber's wires, taking into account, of course, that but a certain fraction of the whole current has been shunted through the meter.

It is clear that if this cell alone were used it would be easy for both consumers and employees to tamper with

the zincs and alter the indications. For this reason the second cell is made accessible to the upper inspectors of the company alone, and these visit the meter once in three months and obtain the indications of the second cell, which should, of course, tally with those of the first.

In order to avoid as far as possible the disturbing effects of polarization, zinc and zinc sulphate have taken the place of the copper and copper sulphate first used, and the zincs are made as pure as possible. They are also covered with chemically pure zinc by electro-deposition, and are then amalgamated with mercury.

The object of the lamp is to raise the temperature in case it should become reduced below a certain degree. When this occurs a compound expansion-bar, A, placed above the lamp, bends down and automatically closes the lamp circuit, so that the lamp begins to glow. This action soon raises the temperature and causes the bar to again curl up and thus break the circuit.

It may be again remarked that this is not properly a work-meter, but merely a current-meter; but that it may be used as a work-meter with considerable accuracy, if the difference of potential is kept at a constant point, and the work be calculated upon the assumption that the potential is always so kept.

Edison's Electric Counter-Meter.—This device is an elaboration of the one just described, in that mechanical means are employed to register the amount of zinc deposited, and, therefore, the number of coulombs of current that have passed. As will be seen from Fig. 165, this apparatus also consists of two electrolytic cells containing two electrodes. One of the electrodes of each cell is the jar itself, the other electrode being a cylinder of the same metal hanging from one of the arms of the balance. The electrical connections are so made that while, in the cell under the depressed arm of the balance, the inner surface of the jar is the cathode and the inner cylinder the

anode, in the other cell, under the elevated arm of the balance, the inner surface of the jar is the anode and the inner cylinder the cathode. Thus the cylinder hanging from the lower end of the balance is losing weight, and

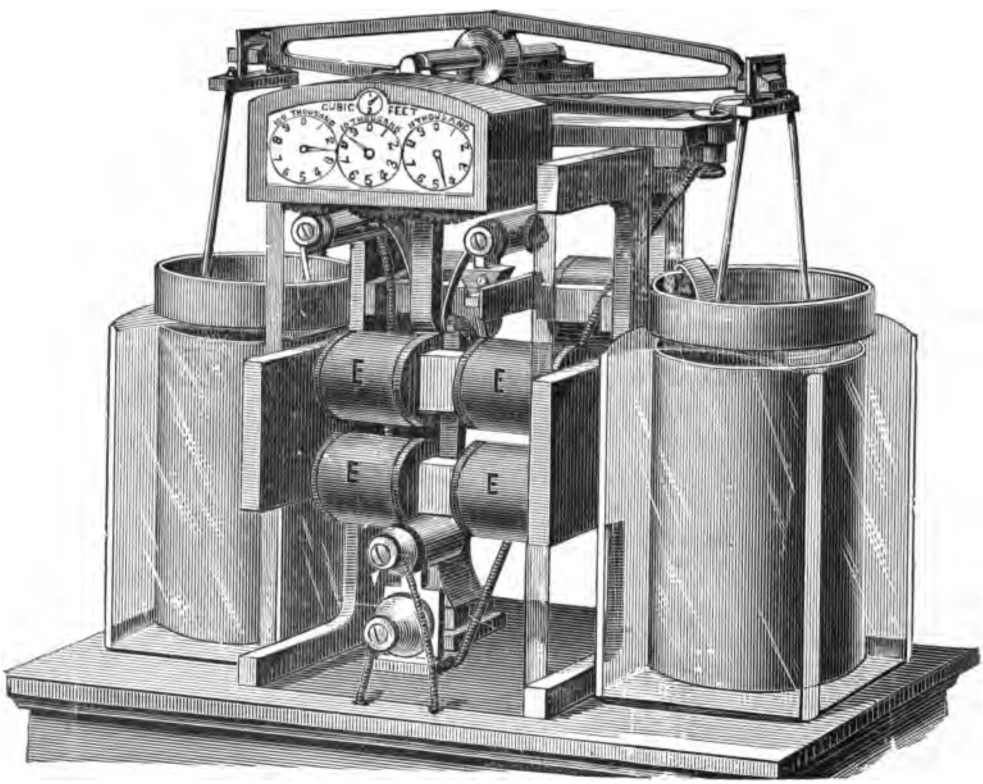


Fig. 165.

that hanging from the upper end is gaining weight. When the weight of the cylinders becomes equalized the lower arm begins to rise. This establishes an electric circuit through the electro-magnets, E, which throws the balance the other way and reverses the current; so that a reverse deposition follows, and continues until the cir-

cuit is again established by the lower arm rising, when the balance is again reversed. As each reversal is registered by an ordinary counter upon the dials, and as each reversal follows the deposition of a definite amount of

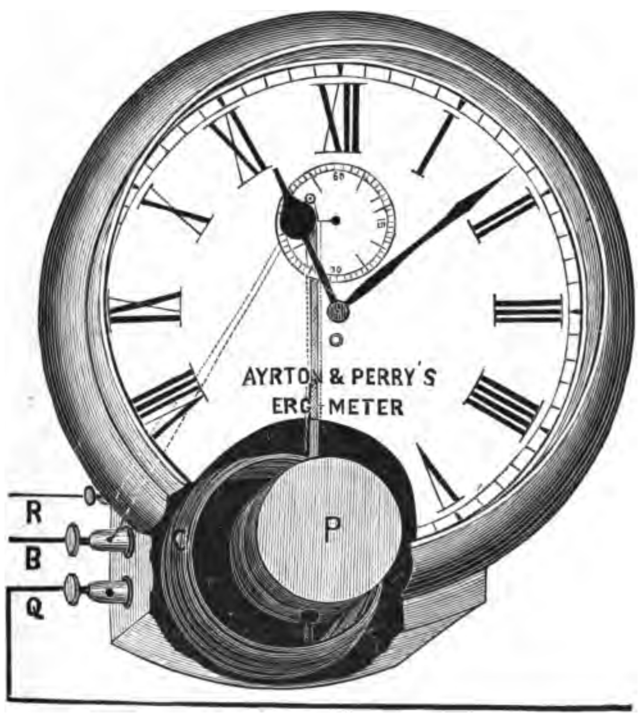


Fig. 166.

metal, it is obvious that the dial registers the quantity of current that has passed.

Ayrton and Perry's Erg-Meter.—This instrument is designed to indicate directly the amount of electrical work that has been furnished to any part of a circuit, the inventors claiming that it is practically an impossibility to preserve such constancy of potential in all

parts of the circuit as to warrant the use of current-meters as measurers of work.

Fig. 166, taken from the London *Electrical Review*, represents a pendulum clock in which a coil of fine wire of high resistance, P, takes the place of the pendulum bob. Directly behind the coil, and secured to the frame of the clock, is a coil of coarse wire, C, traversed by the main current, which enters by one of the binding-posts B Q, and departs by the other, and then goes through the building whose supply the meter is to measure. The binding-post B is connected also to another wire which, as shown by the dotted line, passes up to the axis of the pendulum, then through the coil of fine wire and up on the other side of the pendulum, then down to R, whence it goes to the other main, if the lamps are supplied in multiple arc, or to the house main where it leaves the house, if they are fed in series.

The strength of the current in the coarse coils is, of course, that of the current supplied to the house, while the current in the fine-wire coils depends upon the difference of potential between the extremities of the shunt wire, and therefore upon the potential supplied to the house. The attraction between the two coils depends, as we have before seen, upon the product of the currents traversing them, and therefore upon the product of the current and the potential supplied to the house. But we know that current multiplied by difference of potential is power. Therefore the attraction between the two coils at any instant is a measure of the power being supplied to the house at that instant.

To add up the power indications and get work indications is the office of the clock. Supposing the clock, if undisturbed, to keep perfect time, it is clear that the disturbing influence of the attraction between the two coils will vary in amount according to the attraction between the two coils—*i.e.*, according to the power. Therefore

the *amount* of *correction* which the clock requires at the end of a certain period is a measure of the amount of work done during that period.

The Siemens Power Meter.—This instrument holds the same relation towards a work-meter that a galvanometer does towards a voltameter, as it indicates, not the amount of work that has been done during a given interval, but the rate at which work is being done at any instant.

The instrument consists principally of two coils, one of coarse wire in the main circuit, the other of fine wire in a shunt which is connected to the main circuit at the extremities of that part for which the indication of power expended is desired. The fine-wire coil is usually fixed, and the coarse-wire coil movable, being suspended by a torsion-wire. Their joint attraction for each other (or joint repulsion in case the current is sent through them in opposite directions) gives a measure of the power (CE) being expended in that part of the circuit between the ends of the shunt wire. The coarse coil being hung by a torsion-wire, the milled head at the top can be moved around the graduated dial until the torsion balances the attraction or repulsion. The reading is given in watts on the dial.

The Ohmmeter.—The ohmmeter, devised by Professors Ayrton and Perry, may be said to be the converse of a power meter, because the latter measures $E \times C$, while the former measures $\frac{E}{C}$. $(C = \frac{E}{R} \therefore R = \frac{E}{C}.)$

In this instrument (see Fig. 167) two coils are used, as in work and power meters, one coil traversed by the main current, the other by a shunt current flowing between the extremities of a conductor whose resistance is sought. Instead of acting upon each other they act on a needle in opposite directions, the coils being both fixed, with their axes at right angles to each other. Therefore when the

main current alone is sent through by connecting the conductor to the outer and larger terminals, B B, the needle, on which there is no other directive force, sets itself along the axis of the coarse coil. But when the shunt current is sent through the fine-wire coil by means of the binding-posts C C, the force of this current opposes that of the main current with a strength depending upon the differ-

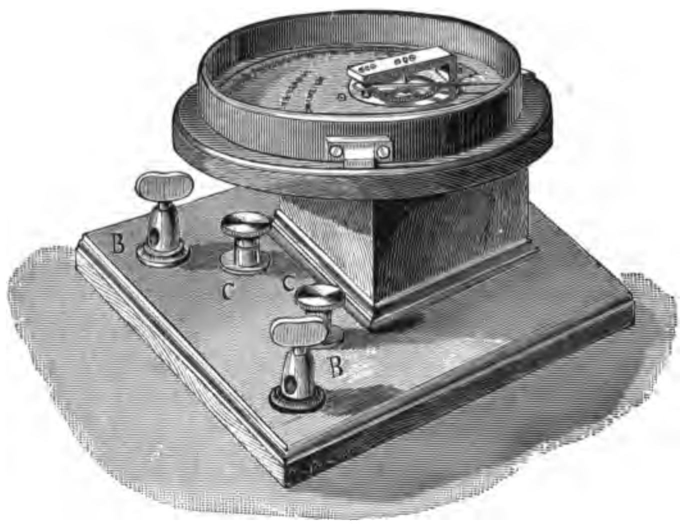


Fig. 167.

ence of potential between the two ends of the shunt, and therefore on the resistance of the conductor between the two points of attachment of the shunt. The greater the resistance, therefore, the greater the deflection of the needle. In order to get wide deflections of the pointer it is mounted upon a pinion engaging with a rack connected to the axis of the needle, the radius of the pinion being much smaller than that of the rack.

The convenience of the ohmmeter will be appreciated when the difficulty is considered of measuring the resist-

ance of machines and of arc and incandescence lamps when in operation, and when the inaccuracy is considered of measuring their resistance when not in operation and cold, and then endeavoring to calculate the difference in resistance that would be occasioned by a rise in temperature. Another difficulty surmounted is that due to the unavoidable errors that must result from the use of resistance-coils when used with large currents, due to their becoming heated; for although German silver does not change in resistance as much as some other metals do, yet it does so to some extent, so that when powerful currents are sent through resistance-coils a considerable element of error is thus introduced. To use the ohmmeter it can be placed in any convenient part of the main circuit, and the resistance of any part of the circuit can then be obtained by attaching the ends of the shunt wires to the extremities of that part.

CHAPTER XVIII.

ELECTRIC RAILWAYS.

THERE are two general systems for propelling cars by electricity. In one system storage batteries are carried by the car and actuate a motor connected mechanically to the driving-wheels. In the other the necessary electrical energy is transmitted to the motor by the rails of the track or by an auxiliary conductor. Each system has its advantages and its disadvantages. In the former method the principal disadvantages are the great weight of the storage batteries, and the fact that they return only a fraction of the power stored in them. In the latter system the principal disadvantage arises from the fact of the unavoidable loss in transmitting the energy along the rails, both by leakage and by heating them. The results already secured with electric railways, however, are such as to lead to the hope of their ultimate adoption in practice. The facts that steam railway locomotives are far from economical, and that an electric locomotive makes no smoke and little noise, and that it weighs much less and therefore requires less power for its propulsion and exerts less wear and tear upon the tracks, furnish the principal arguments in favor of electric railways; and to these must be added the additional arguments that since electro-motors can be made very small, simple, and light, one can operate each car, so that any number of cars can be run independently.

The lightness of these cars allows of their being started and stopped with great readiness, and thus reduces both the danger of collision and the disastrous effects of

collision should one occur. For the impact of two of these light cars would clearly be a much more insignificant thing than that of two long trains with their ponderous locomotives carrying fire and steam. For underground lines and tunnels, in which the smoke of locomo-

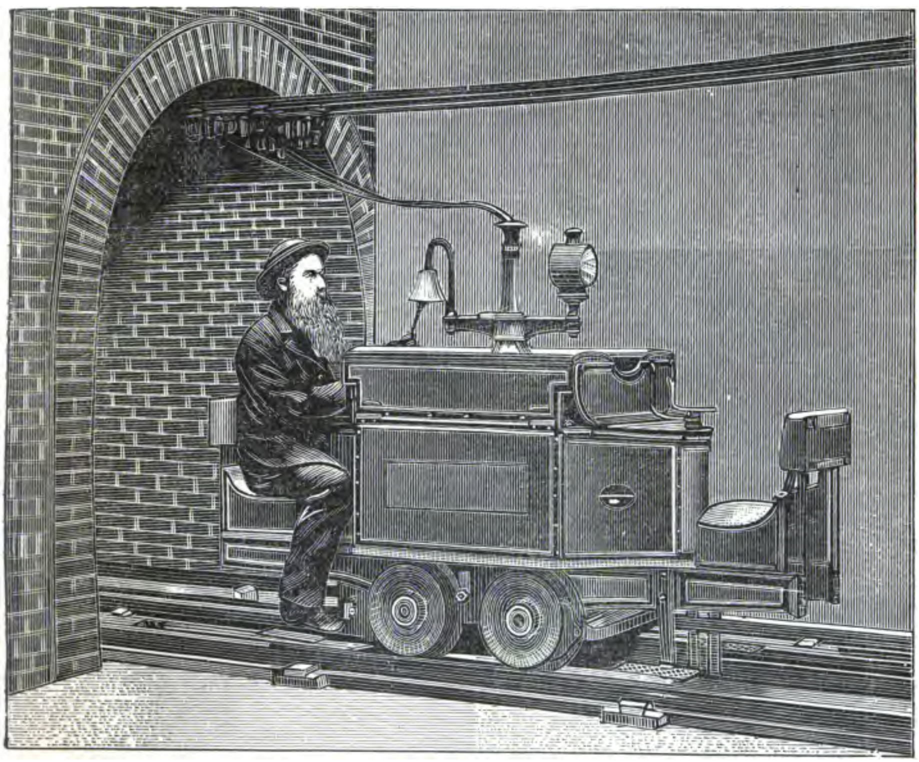


Fig. 168

tives is most oppressive, the advantages of the electric railway are too obvious to require detailing; in fact, electric railways can be used in some underground work where steam could not possibly be made practicable, as in the mines at Zankerode.

Fig. 168, taken from the London *Electrical Review*, rep-

resents the electric engine and railway employed in these mines, and constructed by Messrs. Siemens Brothers. The current is transmitted from the dynamo along the roof of the tunnel through the inverted T-rail shown, upon which slides a contact-carriage connected to the motor on the car by the flexible conductor, also shown. The return current coming from the dynamo is taken to a similar inverted T-iron parallel to the first, which acts as the return conductor. The reason for using separate conductors for both direct and return current is that the track is of necessity so roughly made that its electrical conductivity is small and its insulation poor. The motor, a Siemens machine, is placed lengthwise upon the car, and through suitable gearing turns the driving-wheels which propel it. The gauge of the line is said to be eighteen inches, and the motor to develop sufficient power to draw a load of eight tons at the rate of seven and a half miles per hour.

The first electrical railway was built at Berlin in 1879. It was about three hundred and fifty yards in length, and laid upon wooden sleepers, an auxiliary rail being fixed midway between the two main rails. The auxiliary rail carried the direct current, which was taken off by a brush connected to the motor. The current, after traversing the motor, went into the two side rails, which acted as return conductors. One car, carrying the motor, acted as a locomotive and drew after it three other cars. The affair was a practical success, and pointed to a great extension of the use of electric railways.

The next electrical railway was laid from Lichterfelde to the military academy at Berlin, and was afterwards extended to Potsdam. Steel rails lying upon wooden sleepers were used, the rails being connected by short curved straps of iron in addition to the fish-plates, in order to avoid loss of conductivity by bad connections. The auxiliary or central rail was discarded, the current being

transmitted to the motor by one rail and returned by the other.

In order that this may be accomplished in any railway without great loss from leakage, it is clear that very low-tension currents must be used; but it is also clear (remembering the formula C^2R) that using low-tension currents occasions great loss by heating the conductors.

To take up the current from the positive rail, the metallic tires of the wheels, which were insulated from their axles, were put in electrical connection with brass rings upon the axles, but insulated from them, upon which rings pressed friction-brushes connected to the motor.

Electric Street-Cars.—To run electric cars in the streets of cities it is plain that one or two difficulties must be surmounted. As the tracks are to be stepped on by men and horses, and to be driven over by carriages and carts, they must lie close to the surface of the ground, and, therefore, they cannot be insulated well, except at great expense. For this reason, and on the score of safety, it is necessary to use currents of low tension; but to do this on lines of average length would occasion enormous loss of energy in the rails. To overcome these difficulties two systems have been tried, one that of Dr. Siemens, the other that of Mr. Stephen D. Field, of New York.

In the system of Dr. Siemens a naked conductor is run along on posts near the track, and upon this conductor runs a little contact-carriage, connected to the motor by a flexible cable, and having good contact with the conductor. The most extensive railway operated under this system is the Portrush railway, in Ireland; and as the character of the surface and the surroundings are far from favorable in many particulars, the excellent results secured would seem to offer indisputable proof of the practicability of electric railways for considerable distances. A very clear description of the details of this railway may

be found in the lecture of Dr. Hopkinson, read before the Society of Arts, April 11, 1883. The track runs from Portrush to Bushmills, a distance of six miles, over a country far from level and in a direction far from straight. The grades in some places are as great as one in thirty-five, and the curves are numerous and abrupt. The track is crossed at intervals by paths, and the rails are nearly flush with the surface of the ground.

The auxiliary conductor consists of a T-rail of iron, which runs along on short posts which have been soaked in pitch to reduce their conductivity; and, in addition, the T-iron is insulated from each post by caps of insulite.

As the conductor is about seventeen inches above the ground, it is necessary, at points where paths cross the track, to sink the conductor below the surface, and yet to preserve the electrical connection between the motor on the car and the dynamo.

This is accomplished by having two brushes on the car, one projecting from the forward end and the other projecting from the rear end, both of which brushes press upon the naked conductor. The brushes consist of steel springs carried by stout bars projecting from the car, and are so arranged that when the car comes to a gap the forward brush makes contact with the conductor beyond the gap before the rear brush has broken contact with the conductor behind the gap. When a gap is reached which is too wide to be thus bridged over the engineer breaks the circuit before reaching it, and allows the momentum to carry the car beyond the gap to a position where connection is again made.

The current, on reaching the car, goes to a commutator, which consists of a set of resistance-coils arranged in a circle, and so connected with a lever pivoted in the centre that by moving this around it makes contact with the ends of each resistance-coil in turn, and short-circuits it, or introduces it. By this means the resistance of the cir-

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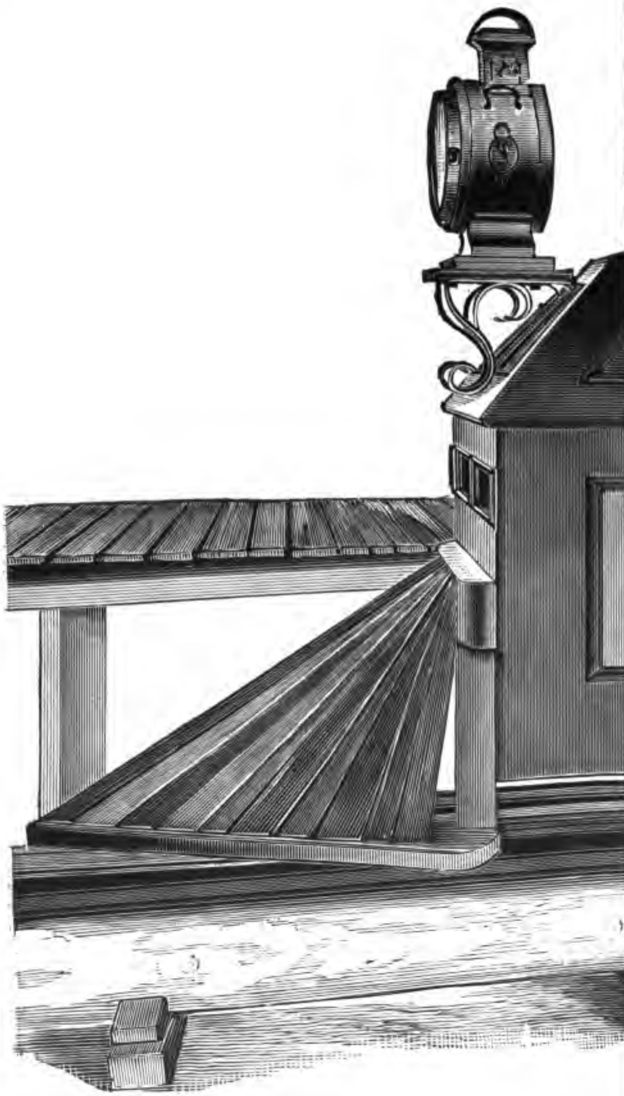


cuit is increased or decreased, and the strength of current regulated.

After then passing through the motor the current goes to the axles, thence to the tires of the wheels, and thence by the uninsulated rails back to the machine. In order to increase the conductivity of the rails by guarding against the imperfect contacts made by the ordinary method of joining rails, they are joined by copper wires in addition to the fish-plates.

The motor is not on the same axle with the driving-wheel, but is connected to it by intermediate gearing in the ratio of seven to one. By this means greater efficiency is clearly attained; for, with the relatively low speed at which car-wheels turn, the counter-current set up by the motor would not be great enough unless it were geared as described.

In Mr. Field's system the raised conductor is discarded, as it would be clearly impossible to use it in a city, and a sunken conductor is substituted. This conductor lies in a large trough running between the rails, and over the trough is laid a cover, along which runs a slit too narrow to allow a carriage-wheel to get in. On the conductor rests a contact-carriage, kept in good electrical connection with it by both rollers and brushes. A strong metal plate attached to the contact-carriage extends up through the slit; to this plate the car is connected, and by it the current passes to the motor. After leaving the motor the current passes to the uninsulated rails and thence back to the machine.

The system of Messrs. Field and Edison was shown in successful operation at the Chicago Exposition of Railway Appliances, running 118¾ hours and carrying 26,805 passengers. The motor was mounted upon a separate locomotive, of which a general view is given in Fig. 169, taken from the *Electrical World.* The track around which this locomotive drew its car, crowded

with passengers, was of the shape and size indicated in Fig. 170, the unfavorable shape being due to the fact that the track was laid around the gallery of the exposition building.

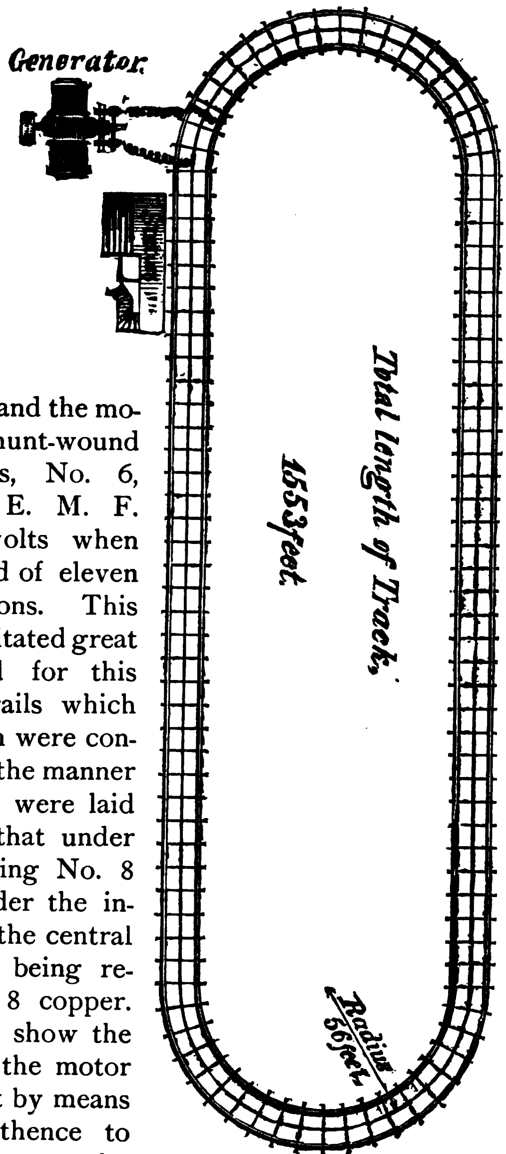


Fig. 170.

The generator and the motor were both shunt-wound Weston dynamos, No. 6, having each an E. M. F. of seventy-five volts when running at a speed of eleven hundred revolutions. This low-tension necessitated great conductivity, and for this reason the two rails which acted as the return were connected together in the manner shown, and wires were laid under each rail, that under the outer rail being No. 8 iron and that under the inner No. 6 copper, the central rail's conductivity being reinforced by No. 8 copper. Figs. 171 and 172 show the connections from the motor to the counter-shaft by means of gearing, and thence to the loose pulleys on the

driving-axles by means of two belts, one for each set of pulleys.

Fig. 173 shows a rear end elevation of the locomotive, G G being the loose pulleys on the shaft with the driving-wheels, W W. F F and F_1 F_1 are cone friction-pulleys, which are so keyed to the shaft as to revolve with it, but to be capable of being moved along the shaft by means of the lever, B, thus forcing the cone-wheels, F F and F_1 F_1, in and out of engagement with the loose pulleys, G and G. When forced into engagement by the movement of the lever the motion of the pulleys is thus communicated to the driving-wheels and the locomotive started. The arrangement for taking off the current is shown at the bottom of the figure, the two brushes, M, of phosphor-bronze wires being pressed against the middle rail by the spring, S.

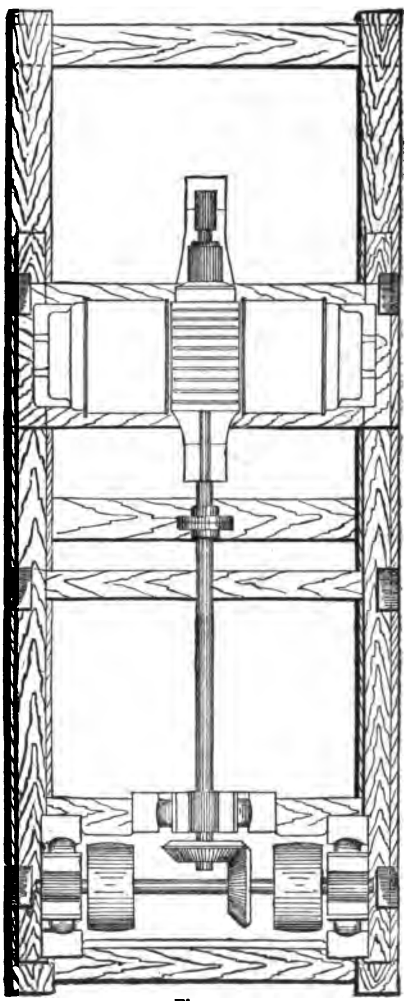


Fig. 171.

A difficulty was at first experienced in starting, owing to the fact that, as the generator was shunt-wound, the

external resistance was at first so slight as not to allow a sufficient current to be shunted for energizing the field-magnets. To obviate this difficulty Messrs. Rae and Healey devised the arrangement clearly shown in Fig. 174, by which the resistance in the circuit was controlled by the movement of the lever, in charge of the engineer. By this device the engineer was able to divert a strong enough current through the field-magnets to generate a good current and start the motor, when its counter E. M. F. acted like a resistance. After the motor had gotten up a rotation the lever was moved to the point shown

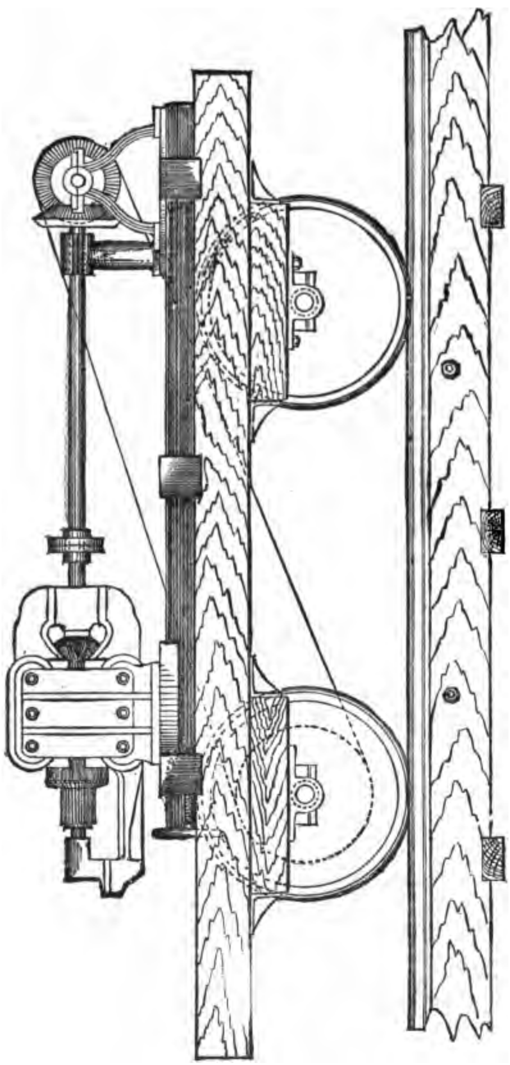
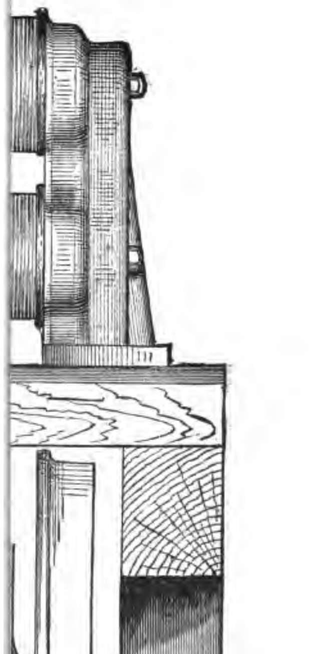


Fig. 172.


W
R

by experience to be the most effective, and then, by means of the lever, B, shown in Fig. 173, the cone-pulleys were forced into the loose pulleys, and the locomotive was started.

It will be remembered that it was shown, in speaking of shunt-wound motors, that if the direction of the external current were reversed the direction of the motor's rotation would remain unchanged. To reverse such a motor, then, some other device is necessary. In the case in question the device shown in Fig. 175 was used, by means of which the current in the armature could be

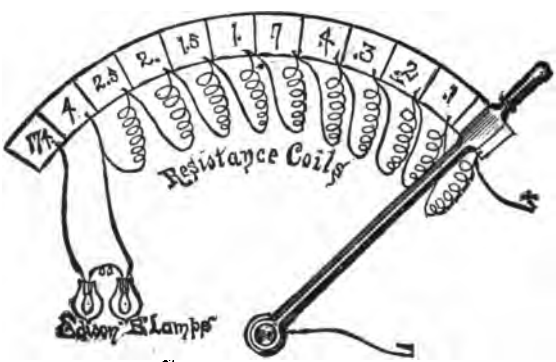


Fig. 174.

reversed, while that in the field-coils was unchanged. The action is clearly shown. The current in the position of the lever shown enters the armature by the brush B^2 and leaves by the brush A_2. By moving the handle to the position K the current is broken, both pairs of brushes being removed from the commutator, H. By continuing the motion the brushes A^1 and B_1 are pressed against the commutator, H, so that the current enters the armature at B_1 and leaves at A^1. By means of the three levers, then, shown in Figs. 173, 174, and 175, the locomotive was kept under complete control.

An electric bell having a resistance of about three hundred and fifty ohms was placed in the locomotive, being

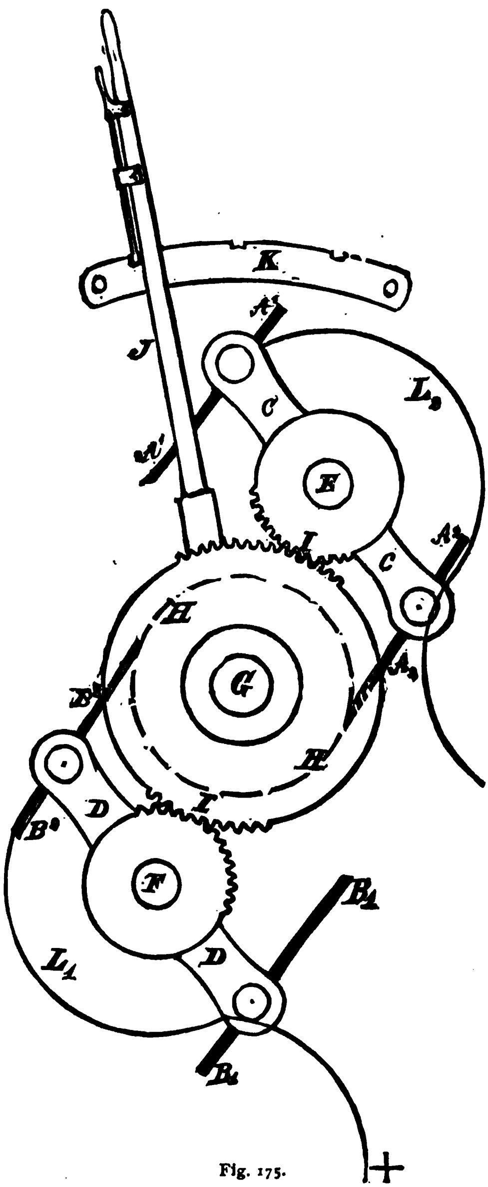
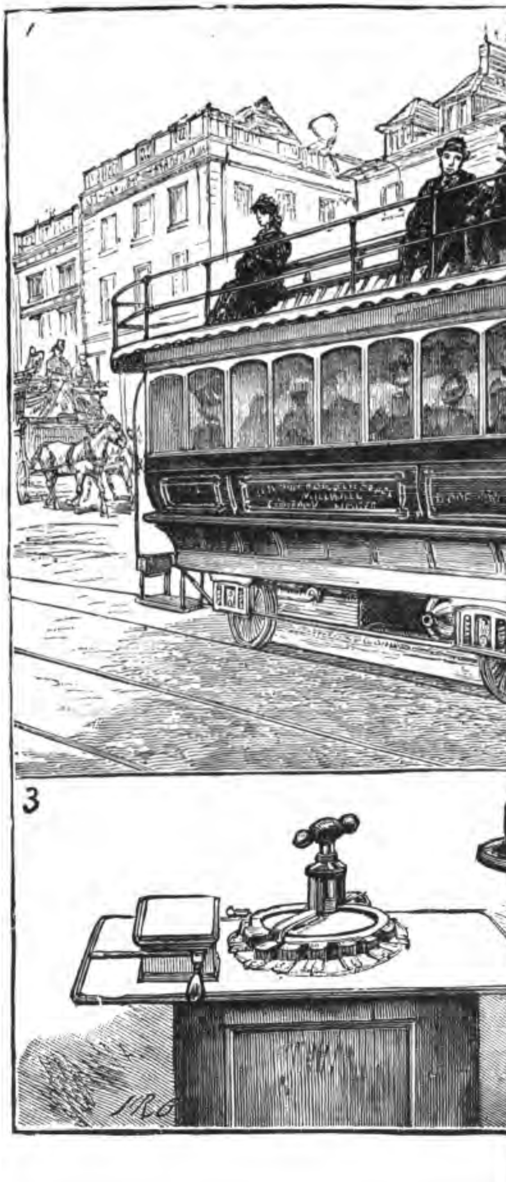


Fig. 175.

in multiple arc with the motor. Having so high a resistance relatively, it of course diverted only an insignificant current from it.

Owing to the weakness of the gallery supporting the track it was not prudent to run the locomotive faster than eight miles an hour, though a speed of twenty-two miles is said to have been sustained for a short while.

THE ACCUMULATOR SYSTEM, in which the electric energy is derived from accumulators carried by the car itself, was recently tried by the Electrical Power Storage Co. of England. An old tram-car was used, the accumulators, fifty in number, being placed upon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a frame resting on the axles. A general idea of the connections and arrangements may be got from Fig. 176. The accumulators rest upon tracks in such manner that they can be taken out and put in with ease from the end of the car.

The motor is not on the driving-axle, but is connected to it by a driving-chain which acts as reducing gear, so that the motor (a Siemens dynamo) may revolve at a higher rate than that of the driving-wheels; for as a speed of eight miles per hour is the maximum allowed, it would be far from economical for the motor to revolve at so low a speed as this would necessitate in the driving-wheels.

A trouble is experienced in starting an electrical car from the fact that before the motor has attained momentum the current is very strong. Although this condition is very favorable in one way from the fact that the energy is at a maximum at the time when energy is most needed, it is very unfavorable in another way from the fact that the excessive current heats the wires and endangers their insulation; for the motor must be constructed to work with the current which exists when the car is in motion, so that there is a limit to the size of wire which can be used. In order to overcome this difficulty numerous devices have been tried. One is to start the motor unloaded, and, when it has acquired momentum, gradually tighten the driving-belt, so that motion is gradually given to the driving-wheel. Another is to turn on the current gradually by taking out one resistance after another, so that the full strength of the current is not sent through the motor. A third way, somewhat similar to the first, is that adopted with the car in question. The driving-belt consists of a steel chain on which are secured at intervals pieces of hard rubber and leather, which is gripped between two pairs of cone discs. These are so connected with a lever on the platform which works the brakes also

that the cone discs at the counter-shaft are drawn toward each other at the same time that the pair on the driving-shaft are separated, and *vice versa*. When it is desired to start the current is admitted, causing the electro-motor and fly-wheel to take up a rapid revolution. The lever is then so operated as to take off the brakes and move the cone discs on the driving-shaft nearer and nearer together, and those on the counter-shaft farther apart. The diameter of the driving-surface thus increases and that of the driven surface decreases, so that the load upon the motor is gradually increased and the car started by degrees. By means of this variable gearing the speed of the car can be governed mechanically. In going up an incline, where the load becomes of course greater, the speed of the driving-shaft is decreased, and therefore that of the car; so that the load upon, and the speed of, the motor are not much affected. The fifty accumulators, it is stated, have an aggregate E. M. F. of 107 volts. It is intended that the dynamo shall work with an electro-motive force of 100 volts and a current of 60 ampères, so that its electrical horse-power shall be

$$\frac{100 \times 60}{746} = 8 +$$

Supposing the efficiency of the motor to be 80, it can then exert a mechanical horse-power upon the car of 6.4 +.

Calculations for Horse-Power, etc.—In order to find the proper dynamo, current, motor, etc., to be used on an electric railway, it is necessary to first determine the horse-power which the motor must be able to exert in order to drive a car of a given weight at a given speed over a given grade. This horse-power can be conveniently obtained by first calculating the force necessary to be exerted, and then introducing the elements of time and distance.

On a straight and level road the resistance of a train due to friction may be taken as eight pounds per ton. In drawing it up a grade the resistance due to the ascent depends upon the steepness of the grade, and is governed by the laws of the inclined plane. In Fig. 177 the work of drawing the weight, W, up the incline is (disregarding friction) exactly equal to that of raising it directly through the height h; but the force to be exerted at any instant depends upon the angle of the incline and is proportional to its sine, $\frac{h}{d}$. For if a weight, W, rest upon the incline the force of its weight may be resolved into two forces, a and d, one perpendicular to the plane, the other parallel to it. The latter force is that which tends to make W slide down the plane, and is clearly equal to w multiplied by the cosine of the angle dWc—that is, to the sine of M, or $\frac{h}{d}$. The total resistance presented to drawing a train up an incline is clearly equal to the friction plus $W\frac{h}{d}$.

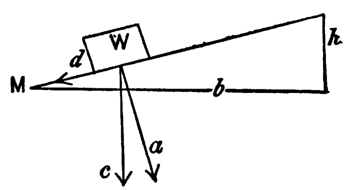

Fig. 177.

Let $F = \frac{W}{n}$, in which F is the friction and n is such a quantity that $n = \frac{W}{F}$. Then $R = W\frac{h}{d} + \frac{W}{n} = \frac{(hn + d)}{dn}W$. In case F is taken as eight pounds, $n = \frac{2240}{8} = 280$.

High winds and abrupt curves increase the value of F, as does also the resistance of the atmosphere, particularly at high speeds. $\left(F = 8 + \frac{V^2}{171}\right)$ The real value of F, and therefore of n, depends, then, it is clear, upon the shape and size of the car, the speed, number and abrupt-

ness of curves, etc. Tables of the values of F may be found in engineering tables.

Knowing now the *force needed*, and desiring to know the work needed per hour, it is only necessary to multiply the force by the speed to be attained per hour in feet. To get from this the horse-power divide the result by 1,980,000, the number of foot-pounds in one horse-power per hour.

Suppose we wished to know what horse-power a motor must develop in order to draw a car weighing four tons up an incline of two in one hundred at a speed of thirty miles per hour, the resistance from friction, wind, curves, etc., being 20 pounds per ton.

$$F = 20 = \frac{W}{n}. \quad n = \frac{2240}{20} = 112.$$

$$R = \left(\frac{hn + d}{dn} W\right) = \frac{2 \times 112 + 100}{100 \times 112} \times 4 \times 2240 =$$

$$\frac{324 \times 4 \times 2240}{11200} = 259 +.$$

$$\text{HP} = \frac{259 \times 5280 \times 30}{1{,}980{,}000} = 20 +.$$

Knowing the horse-power which the motor must develop, and knowing the greatest current that the conductor can carry without losing more than the prescribed amount, it remains to calculate the electro-motive force which the motor must develop. Supposing the electrical efficiency of the motor to be eighty per cent., then

$$H = \frac{CE'}{746} \times \frac{80}{100},$$

because the counter electro-motive force generated by the

motor multiplied by the current traversing it measures the *electrical* work it performs. Then

$$E' = \frac{H \times 746}{C} \times \frac{100}{80}.$$

In order to find the E. M. F. of the generator E,

$$\frac{E}{E'} = \frac{W}{W'} = \frac{CE' + C^2R}{CE'} = 1 + \frac{CR}{E'}$$

$$E = E' + CR.$$

Dyne unit of Force =

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